the Daylight Imperative

A THESIS PROJECT BY
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THE DAYLIGHT IMPERATIVE

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ABSTRACT

Hospitals in the US are typically built as thick buildings due to a desire to optimize travel distances and functional relationships within and between clinical and supporting departments. However, this building configuration disconnects building occupants in core work areas from daylight and views to nature. It also promotes high energy consumption due to excessive use of artificial lighting and air-condition. Yet, having access to daylight and the view to nature in buildings is important for human health and wellbeing, especially in hospitals. Daylight regulates the body´s circadian rhythm, is necessary to produce Vitamin D, affects mood, lowers stress, increases concentration, and enables performance of visual tasks. Additionally, having access to daylight can improve the recovery process, it is effective as an antidepressant, and reduces pain. Furthermore, daylit hospitals have a great potential for energy savings, if their design integrates appropriate daylighting strategies and recognition of local climatic conditions.

Future generations of hospital design need to become healthier places to deliver care, and become healthier for the planet by minimizing their significant impact on carbon driven climate change. Therefore, improving access to daylight and connections to nature should be a major design driver for hospital buildings and other large healthcare building typologies to protect the health of building occupants and support the 2030 challenge to protect global health and natural resources.

An extensive literature review was conducted to study the impact of daylight in buildings on human health and wellbeing as well as the potential for energy savings. Architectural typologies used for hospital buildings in the US and Europe were explored for daylight penetration. Current hospital designs illustrate chances and challenges for providing daylight and views to the outside in core clinical areas. The increasingly dense and compressed footprints of US hospitals make it difficult to integrate daylight without moving to more perforated plans or narrow wings as employed in other parts of the world. The study of global best practices, together with literature research, were used as basis for the development of daylight design guidelines for future US hospitals, that meet the requirements of contemporary programs and codes. Guidelines that were developed include 1) Orientation and location, 2) Narrow building footprint, 3) Perforated thick building footprint, 4) Courtyards in patient, staff and public areas, 5) Shading, and 6) Skylights and clerestories in patient, staff and public areas.

A design-proposal for a mid-size [146 bed] community hospital (one of the most common hospital types in the US), implementing the developed daylight-design guidelines, is presented as a test case. The Montgomery hospital replacement project in Norristown, Pennsylvania was picked to implement the thesis proposal on a challenging tight urban site to create a hospital based on the proposed concept:

"Form Follows Daylight".

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> "Bring a little more knowledge, a little more reason, and a little more compassion into world affairs and thereby to increase the chance that nations will learn at last to live in peace and friendship" – J. William Fulbright

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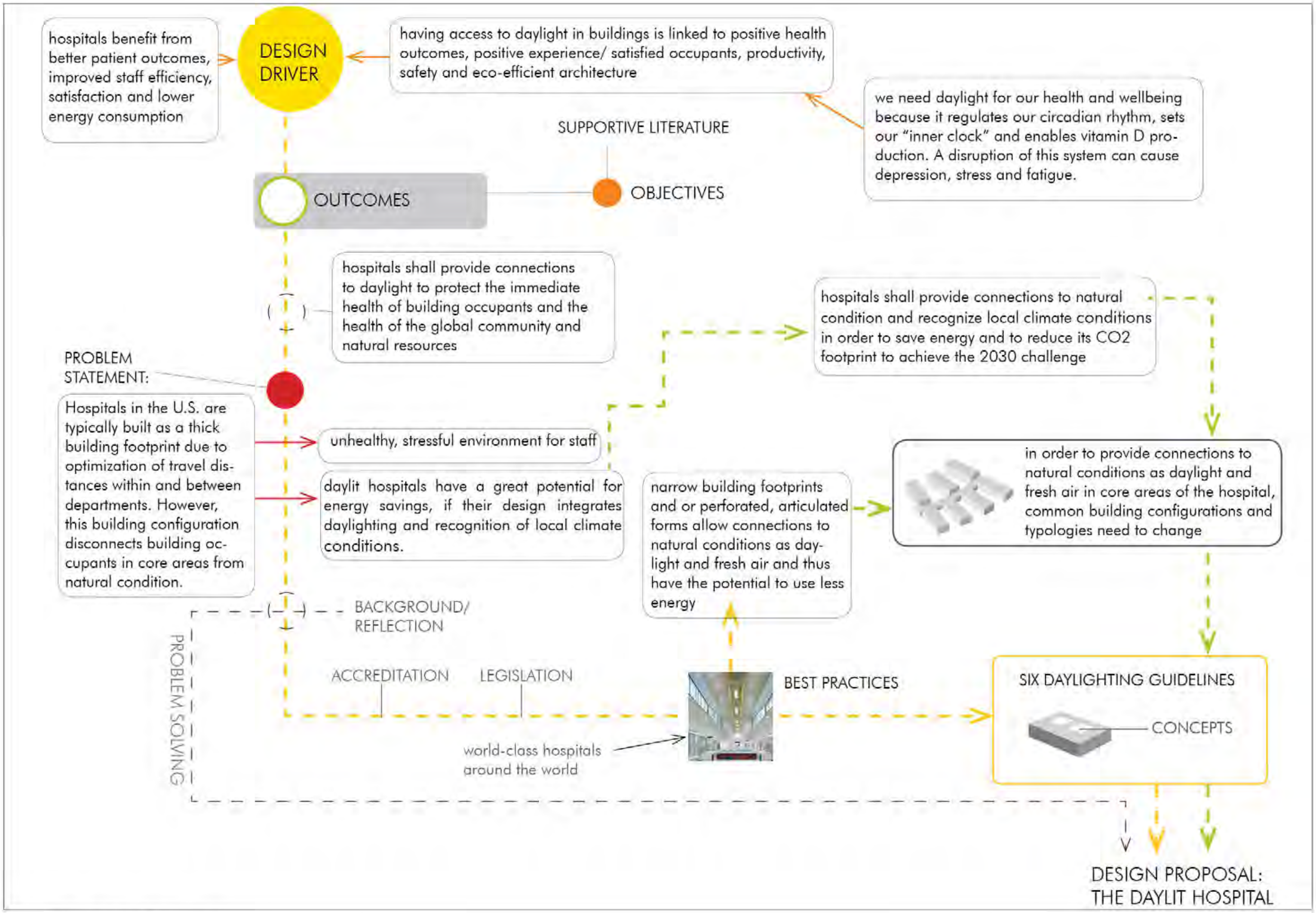


Figure 01: Major claims of thesis.

1 INTRODUCTION

Hospitals in the U.S. are typically built as a thick building footprint. This building form evolved during the mid 20th century when articial light and air-conditioning became available at low costs and direct connections to the outside became less important in the US. Functionalism and efficiency drove optimized travel distances, as well as new medical technologies created rising demands for controlled thermal and

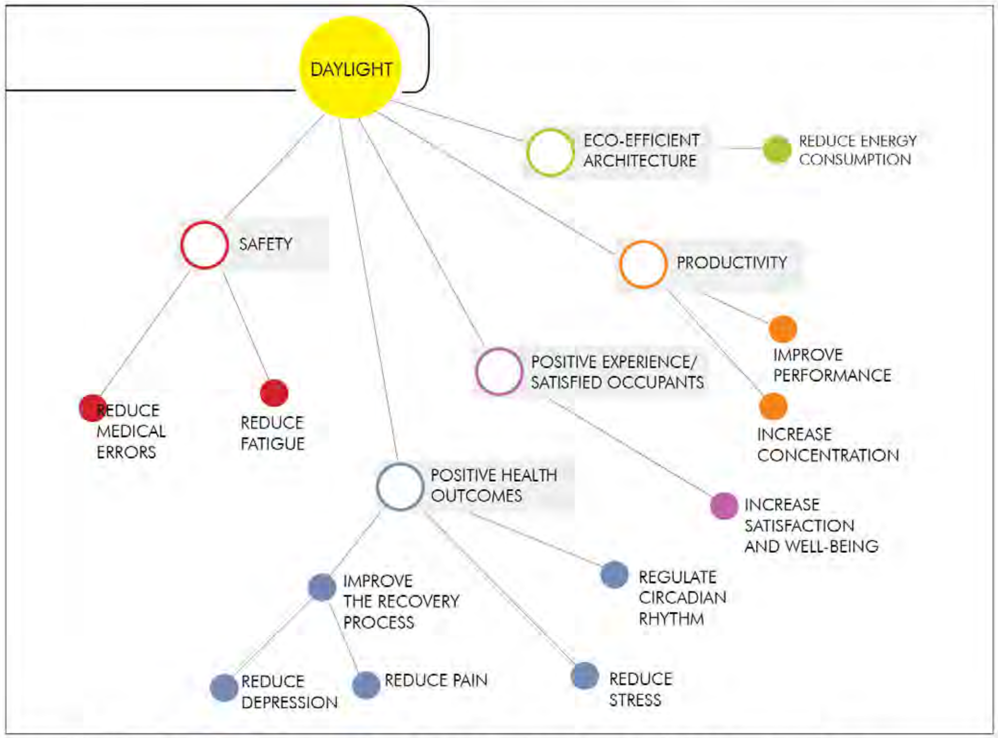


Figure 02: Map illustrating the impact of daylight on health, wellbeing, safety and sustainability.

light environment. This ever expanding equipment intensive and process oriented space resulted in deep planned building shapes. However, these thick building configurations disconnects building occupants in core areas from daylight and views to nature. Yet, having access to daylight and the view to nature in buildings is important for human health and wellbeing. Physiologically, it regulates human circadian rhythm, stimulates the visual system and psychologically, daylight and views to the outside are much desired. According to the biophilia hypothesis, humans have a partially genetic tendency to respond positively to nature (Wilson, E.O., 1984).

Because daylight can be used to illuminate interior space of a building through side lighting, toplighting or guided light systems, daylit hospitals have a great potential for energy savings-, if their design integrates daylighting and recognition of local climate conditions. For present and future generations, hospital design is challenged with the need to reduce greenhouse gas emissions and energy consumption, due to its impact on carbon driven climate change. Therefore, daylight and connections to nature should be a major design driver for hospital buildings and other large healthcare building typologies to protect the health of building occupants and to support the 2030 challenge to protect the global health and natural resources.

Physically, the light of the sun is a source of electromagnetic radiation with a balanced spectrum of colors spectrum ranging from ultraviolet (UV-light) 100 nm to infrared (IR) radiation 10 nm. But only a small part of this light, the range between 380 nm and 780 nm, is visible for human eyes. The characteristics of daylight involves a

Figure 03: Different appearance of daylight throughout the day.

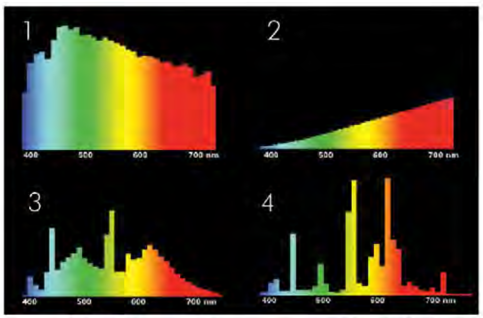


Figure 04: Different color spectrum of 1) daylight, 2) light bulb, 3) fluorescent lamp and 4) energy efficient lamp.

Figure 05: Example for good color rendering (left) and bad color rendering (right).

combination of sunlight and skylight which is constantly changing throughout any given day between sunrise and sunset and over the course of the yearly solar cycle (Figure 03). Daylight changes its color, intensity and direction, depending on the time of day, season and sky cover. This naturally occurring relationship between illuminance and color temperature throughout the day helps regulate human circadian rhythm and is experienced as visually pleasant. Artificial light sources are often concentrated in limited areas of the spectrum (Figure 04: spectrum 2-4). Full spectrum light closely matches the spectrum of daylight, however artificially generated full spectrum is limited to a static representation and does not reflect the dynamics in color and intensity of natural light.

Daylight can maximize visual performance because it contains all wavelengths of the full spectrum in an almost equal intensity in the visible light range (Figure 04: spectrum1), which is the reason for daylight's excellent color rendering (Figure 05). However if daylighting in buildings is not designed properly and the distribution of light is not controlled, human comfort and visual performance and can be negatively impacted due to excessive heat gain, glare and distraction. Also, even though most short wavelength are filtered by glazing, people who are sensitive to ultra-violet radiation can be adversely affected by daylight. Daylighting can also increase energy consumption due to heat gain and increasing internal cooling loads if local climate conditions are not recognized and appropriate screening strategies are applied at the building envelope.

Daylight and Health: Having access to daylight in buildings through sidelighting and toplighting is important for human health and wellbeing. Daylight is the preferred source of lighting, influences humans mood and has a physically stimulative impacts on humans circadian rhythm. The dynamic changes of daylight helps to set our "inner clock" as indicated by several studies about sleep pattern/ depression and concentration (Boyce, P., 2001, Figueiro, M.G., et al., 2002, Heerwagen, J.H., 1998). In addition, a visual connection to the outside through windows allows building occupants to appreciate time of the day, weather conditions and seasons.

Figure 06: Contemporary staff working area in American hospital, disconnected from the outside.

Yet healthcare workers are often disconnected from the outside. This is especially crucial in northern latitudes during the winter season; employees go to work before sunrise and leave work when it is already dark again. If their work environment does not provide connections to the outside, they may not be exposed to daylight for days. This may result in a variety of health problems because daylight has been shown to have numerous impacts on human health and wellbeing -psychological but also physiological. It regulates the body´s circadian rhythm, is necessary to produce Vitamin D, affects mood (Kueller, R. et al. 2006; Harris, P.B. et al. 2002; Kim, J.J. & Wineman, J. 2005), lowers stress (Leather, P. et al. 1998; Alimoglu, M. K., & Donmez, L. 2005), increases concentration (Heschong, L. et al.2003), and enables performance of visual tasks. Thus, the accessibility to daylight within buildings, especially in primary work spaces, can help staff to stay healthy and improve performance on critical tasks within their job as health care providers. Additionally, having access to daylight can improve the recovery process for patients (Beauchemin,

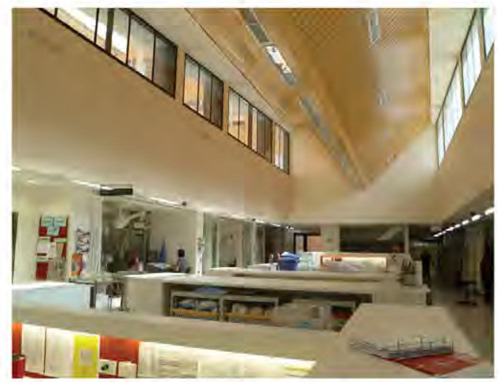


Figure 07: Daylit staff work station with clerestories, Intensive Care Unit of Alfred Hospital, Australia.

Figure 08: Daylit patient room with clerestory and operable window, Children's Hospital Heidelberg, Germany.

K. M., & Hays, P. 1998). It is effective as an antidepressant (Beauchemin, K..M. & Hays, P. 1996; Benedetti, F. et al. 2001) and reduces pain (Walch, J.M. et al. 2005; Malenbaum, S. et al. 2008).

Daylight and Eco-efficient Architecture: Daylighting has great potential for energy savings if the building design recognize local climate conditions. Half of the total energy consumption of the U.S. is used to operate buildings and among all building types, hospitals belong to the most intensive energy user. 40% of the total energy used in hospitals is used for electricity, most of it for lighting.

Hospitals in the future need to implement daylight strategies to reduce energy use, and improve health at the level of individual building occupants, the communities where they are located and globally through reducing carbon driven climate change. This is central to their fundamental mission of improving health and health care delivery. Therefore daylight should be a major design driver for hospital buildings and typologies to both protect the health of building occupants and to support the 2030 challenge to protect the global health and natural resources.

Daylight and the Business Case: It is initially more costly to build an articulated and/ or perforated building with much more daylight availability than a thick building footprint. However this investment will result in long term savings such as energy savings, but also has the potential to lower staff related costs such as staff turnovers due to increased satisfaction, reduced stress levels and increased concentration which also may result in higher productivity and lower error rates.

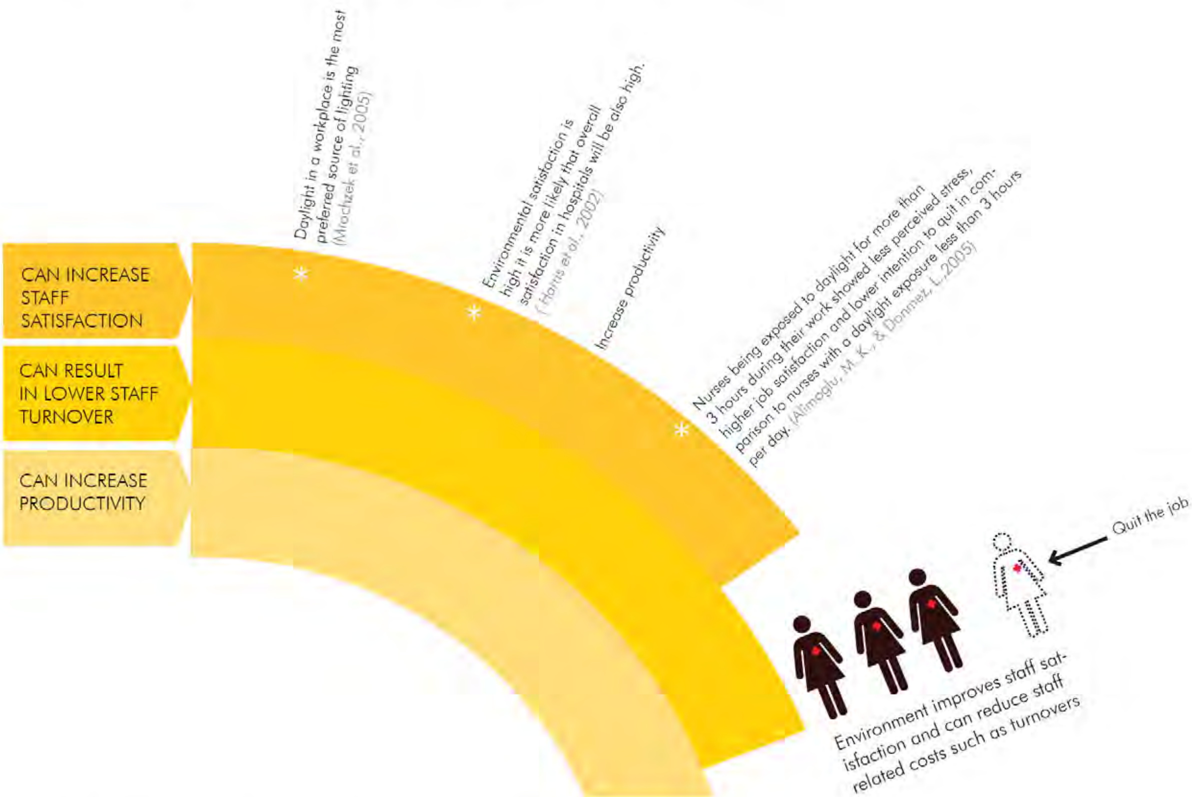


Figure 09: Daylighting and its potential economic benefits.

Daylight and Healthcare Architecture: In most hospitals in the U.S., clinical staff work areas and most other staff areas do not have access to daylight. Even fewer staff work areas have direct views to the outside to experience the time of day and external weather conditions. Common thick building configurations for diagnostic and treatment areas or the race track plan for inpatient units organize their staff area within the core to optimize travel distances to and between functional areas. However this configuration results in disconnection to the outside and thus low daylight illumination rates in staff working areas.

The trend towards thick healthcare buildings during the 20th century was enabled by the development of mechanical air conditioning and cheap energy, and driven by the belief that mechanically controlled environments were healthier. In fact the indoor air quality of most exclusive mechanically conditioned healthcare facilities today is now being recognized as generally poor if not fundamentally unhealthy. The world health organization has published in 2009 a new guideline where natural ventilation is considered for the first time among the effective measures to control infections in health care buildings. (Atkinson, J., et al., 2009)

Another force driving thicker healthcare buildings in the US is the desire for optimizing functional relationships and internal views, and minimizing travel distances for staff. These drivers may be less relevant today when functional efficiency is increasingly less about direct access or visualization from centralized staffing points and time and motion, and more about information technology, decentralized staffing and virtual connections.

Most other developed countries in the world- those with advanced and comparable healthcare delivery to that found in the United States- still design and build healthcare facilities with extensive access to and requirements for daylight, views and natural ventilation. This includes many countries with better health status and health outcomes than in the US. Hospitals in most European countries are required to have narrower building configurations and operable windows that enable occupants to have widespread access to daylight and utilize natural ventilation when exterior weather conditions permit and interior needs can be met without mechanical conditioning. Hospitals in these countries are typically laid out with narrow wings and/or contain courtyards and atria to provide occupants with almost universal access to daylight, views to nature and natural ventilation (Figure 10 Akershushospitalet, Norway and Figure 11 Hospital Agatharied, Germany). These examples from around the world and an emerging number of facilities in the US are demonstrating that hospitals can be functionally efficient and effective places for patient care, environmentally responsible and healthier for all their occupants when they are designed to optimize access to daylight and views to nature. Hospital typologies promoting these connections in patient care, work spaces and public areas are based on narrow building footprints or articulated and penetrated plan forms.

Figure 10: Hospital with narrow building footprint and natural ventilation.

Figure 11: Hospital with perforated and articulated building footprint.

The primary objective of this thesis is to develop building design concepts that reconnect both patients and care providers to natural conditions like daylight and views to the outdoors. Based on research results (Chapter 2: Daylight and Health), environmental awareness (Chapter 3: Daylight and Eco-efficient Architecture) and design review of daylit hospitals around the world (Chapter 4: Daylight and Healthcare Architecture) six daylight guidelines are developed and illustrated by best practice case studies in the second part of the thesis.

The proposed concepts are then applied to a design proposal for a 146 bed replacement community hospital in downtown Norristown, Pennsylvania. This daylit community hospital is designed to address the particular local climate conditions and challenges of a tight urban site to create an efficient hospital with physical and visual connection to nature and daylight. It is intended to demonstrate how daylight can be introduced in US hospitals while addressing the complex planning and context constraints of a contemporary hospital program.

2 DAYLIGHT AND HEALTH

Having access to daylight in buildings is linked to positive health outcomes, positive experience/satisfied occupants, improved productivity and safety. The relationships between daylighting and goals to promote health and wellbeing with their objectives are illustrated in Figure 12. The map also links the objective to supportive literature.

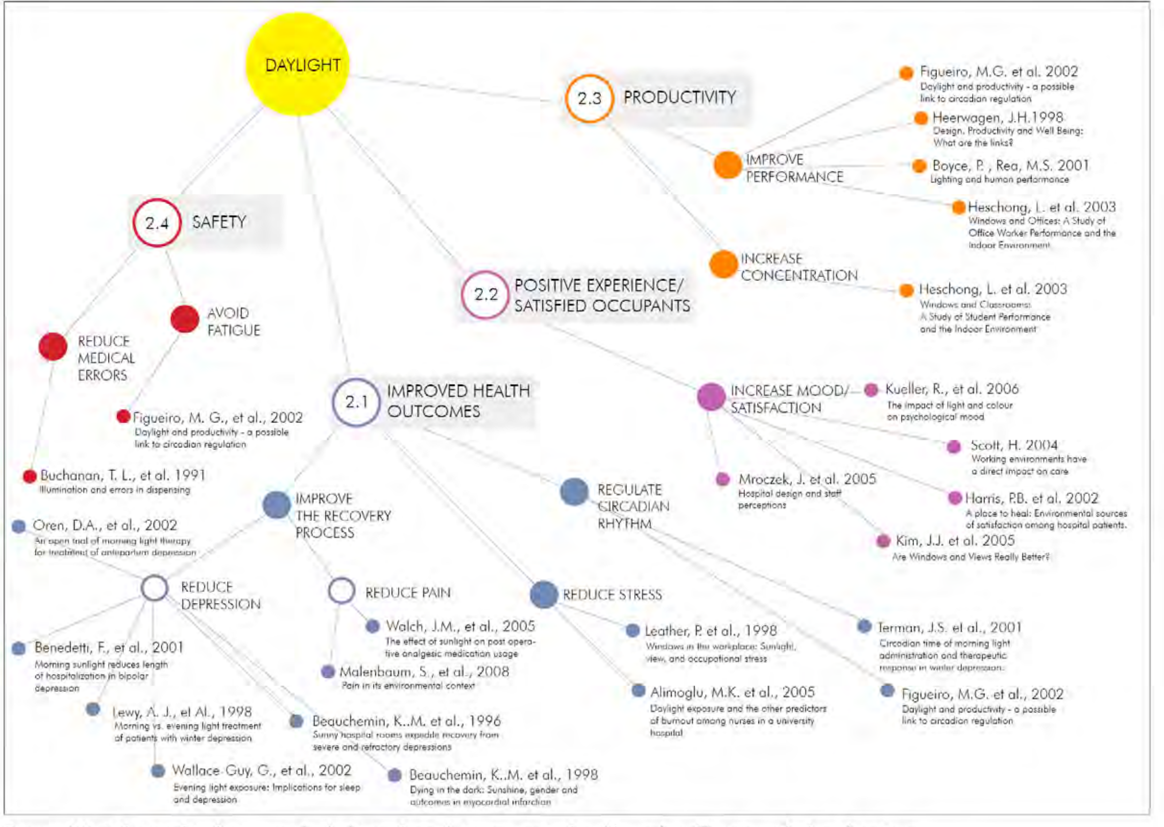


Figure 12: Relationship between daylight and goals to promote health and wellbeing with the objectives.

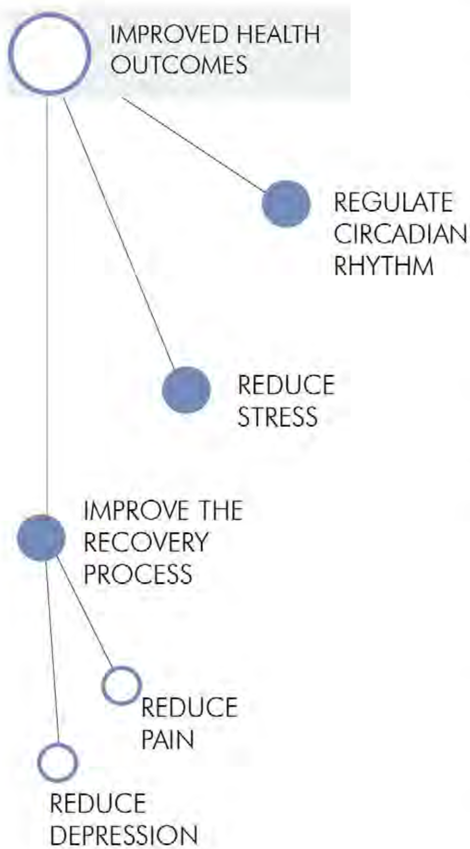


Figure 13: Framework linking goals to objectives.

Healthcare organizations can benefit from better patient outcome, increased satisfaction, improved staff efficiency and productivity as well as lower staff turnover rates.

Studies have shown that daylight is the preferred source of lighting (Joseph, A., 2006); it decreases perceived stress and increases work satisfaction. (Kueller, R., 2006, Mroczek, J. et al., 2005, Alimoglu, M.K., et al., 2005, Scott, H., 2000, and Leather, P., et al., 1998). In terms of patient safety and staff performance, a relation between high illumination levels and medical errors was found. Medication dispensing errors were lower (2.6 %) at an illumination level of 1500 lux in comparison to an error rate of 3.8 % at 450 lux. (Buchanan T.L., et al., 1991). Daylight is an excellent source of bright light levels; on a clear day, the outdoor illumination level is approximately 10,000 lux while inside the building close to the window the illumination level is still approximately 1,000 lux. Furthermore, absence of daylight may result in fatigue and lower productivity (Figueiro, M.G., et al., 2002) due to disrupted circadian rhythms in staff.

2.1 IMPROVED HEALTH OUTCOMES

Daylight plays an important role for the human circadian rhythm because bright light is needed to set the 'inner clock', which is a roughly 24 hour cycle in the body's biochemical, physiological, or behavioral processes (Figure 15). Many health problems are associated with a disruption of the human circadian rhythm. Thus, most of the health outcomes linked to daylight are linked through this relationship. Bright light is needed to set our rhythm, thus artificial light could also be used for regulation, however light levels which are higher than needed for visual tasks are only achieved by installation of more intense luminaires with higher energy consumption, whereby high light levels can be delivered naturally by daylight through side lighting

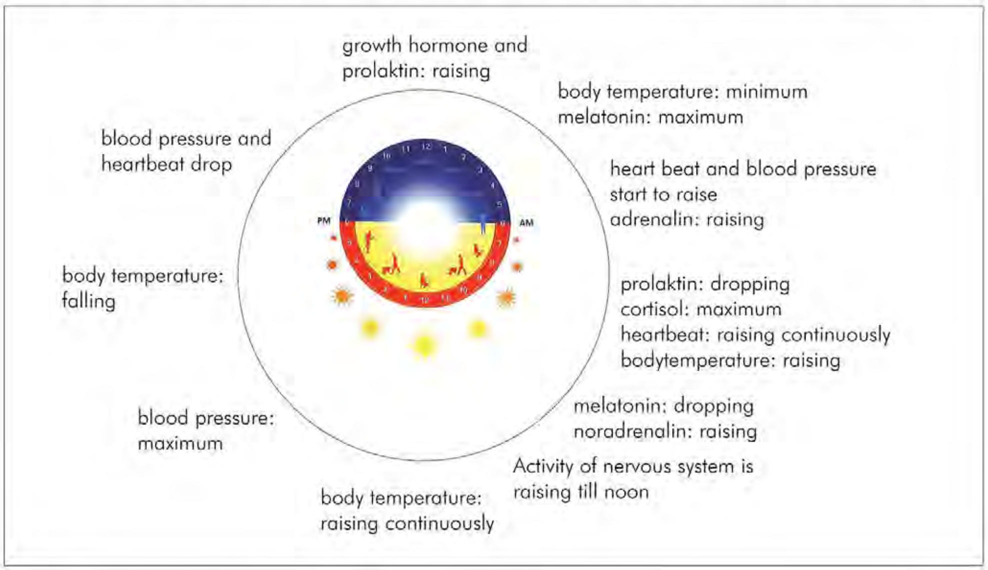


Figure 15: Relationship between the circadian rhythm and body functions.

REGULATE CIRCADIAN RHYTHM

DESIGN APPLICATION
Inpatient Units: primary work spaces and patient rooms,
D&T: primary work spaces, administrations and offices.
RELATES TO GUIDELINE:
building orientation, narrow building footprint, perforated building footprint, courtyards in patient, staff and public areas, skylights and clerestories in patient, staff and public areas

Figure 14: Regulation of circadian rhythm and its applications.

and top lighting strategies. A 300 -500 lux illumination level for critical tasks, for example, results in a light level of 100 lux directly on the eye. However, a light level of at least 300 lux directly on the eye is necessary to have measurable impact on one's circadian rhythm. In an interior environment with side and top daylighting strategies such high light levels are very common within the daylight zone.

The work of the circadian system is complex: the process of melatonin production which serves as circadian messenger to many other systems in our body is regulated by our "master clock" in the suprachiasmatic nucleus (SCN) which is located in the hypothalamus. The hypothalamus has a connection to the retina of the eyes and is responsive to light and darkness. When bright light falls on the retina in our eyes, the SCN regulates the activity of the pineal gland and suppresses or delays secretion of melatonin. During night at the condition of darkness the SCN passes the information to pineal gland to produce secretion of melatonin. Thereby the SCN entrain the system of our "master clock" to a 24 hours rhythm. A disruption in circadian rhythm, for instance work during night shifts with exposure to bright light or working in an windowless room with low illumination levels can cause disruptive sleep/awake pattern and thereby may result in fatigue, lower productivity, lower mood and depression as, for instance, the seasonal affective disorder (SAD) (Figuerio et al., 2002; Boyce, P. 2001)

Reduce Stress: Healthcare staff are inherently involved in tasks that demand high and consistent levels of performance tasks and high concentration to avoid medical errors in patient care, decision making and medication dispensing. At the same time their work performance must be efficient as clinical staff are increasingly being asked to care for more patients, in less time and with better outcomes. As a result, staff in hospital experience high level of stress (Harris et al., 2002) and stress has negative affects on staff performance, satisfaction, burnouts and staff intention to leave the job. (Coomber, B. & Barriball, K.L., 2005). Numerous studies have shown that the work environment has a strong influence on these stress levels. Several studies have shown the importance of daylight to regulate circadian rhythm and improvement of sleep quality and to reduce depression which are all related to predict stress. Nurses that have access to daylight, reported reduced stress levels, increased satisfaction and lower intention to quit. Nurses exposed to daylight for more than 3 hours during their work showed less perceived stress and higher job satisfaction in comparison to nurses with a daylight exposure less than 3 hours per day. (Alimoglu, M. K., & Donmez, L.,2005). Another study of Leather, P et al., 1998 compared the occupational stress, satisfaction and intention to quit of industrial workers in Southern Europe. The study shows that the penetration of sunlight is important for reducing stress and therefore results in higher satisfaction and lower intention to quit. However higher illumination levels from artificial light alone didn't show the same results. Views to nature also were shown to have a buffering effect on negative experience and had positive effects on stress levels as well.

REDUCE STRESS

DESIGN APPLICATION
Inpatient Units: primary work spaces and patient rooms,
D&T: primary works paces, administrations and offices
RELATES TO GUIDELINE:
perforated building footprint, narrow building footprint, courtyards in inpatient units, skylights and clerestories in patient, staff and public areas

Figure 16: Reducing stress and its design applications.

Figure 17: Design proposal for inpatient unit with strong connections to nature, K2 Architects, Finland.

Figure 18: Inpatient room with direct access to roof terrace and natural ventilation, Katta Hospital, Japan.

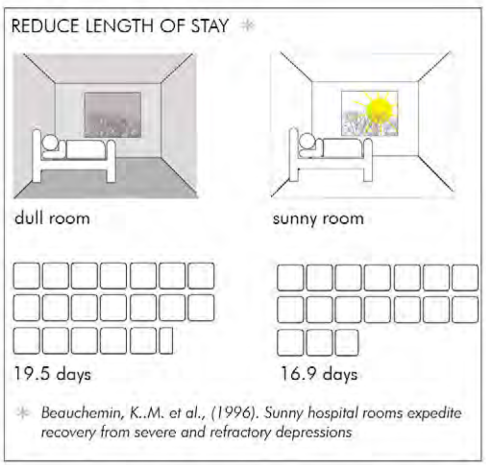


Figure 19: Daylighting and its impact on length of stay.

Reduce Depression: Depression is a serious illness which is widespread and a costly problem in healthcare facilities. (Ulrich, R.S. et al., 2008). A large body of evidence indicates that bright artificial light and daylight is an effective treatment method for depression, improves mood and reduces the length of stay because it regulates the circadian system (Lewy et al., 1998). Light treatment has been shown more effective than antidepressant drugs. Studies suggest that bright light treatment can reduce depressive symptoms after less than 2 weeks while drugs requires at least 4-6 weeks of treatment (Golden et al., 2005).

Other studies indicate that bright artificial light or daylight treatments during the morning are more effective than evening light treatments. The general principle of these results relates to the fact that bright light suppresses or delays melatonin production. A low melatonin production during the day is desired while during the night the melatonin production should achieve its peak in order to maintain a 24 hours sleep/awake pattern. The fact that bright artificial light and daylight reduce depression, shown in a large body of evidence, illustrate the importance of the orientation, building form and site planning of healthcare buildings to maximize access to daylight.

Benedetti conducted a retrospective study showing that patients with bipolar depressions in rooms with eastern facing windows had a mean 3.67-day shorter hospital stay than patients in rooms with western facing windows. (Benedetti et al., 2001)

A study by Beauchemin, & Hays in 1998 indicates that depression is not only limited to patients in mental health facilities. It is also an issue for people with other physical diseases. The study compared the fatal outcomes and length of stay of patients with myocardial infarction treated in sunny rooms and those treated in rooms with limited access to sunlight. It founded that sunny rooms had more positive health outcomes: patients stayed a shorter time in the sunny rooms, but the significant difference was confined to women (2.3 days in sunny rooms, 3.3 days in rooms without direct solar exposure). Mortality in both sexes was consistently higher in rooms without direct access to sunlight (39/335 dull, 21/293 sunny). The result of this study are illustrated in Figure 20.

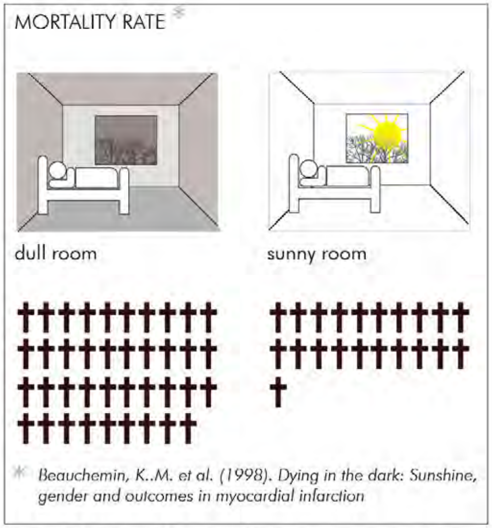


Figure 20: Daylighting and its impact on mortality rate.

Reduce Pain: Nature views may reduce pain based on the distraction theory. The view out of a window to nature as well as simulated views of nature (Figure 21) functions as a positive distraction for patient, lower stress and elicit positive emotions (Malenbaum et al., 2008). A study from Roger Ulrich in 1984 with same results illustrated the importance of nature views. He compared patients with a bedside view overlooking trees with patients looking at a brick wall. The patients with the nature view took less pain medication, their length of stay was shorter, with less complications and they reported higher satisfaction (Ulrich, R. 1984).

Figure 21: Simulative view of nature in patient room.

The pain reduction mechanisms of sunlight differs from the positive impact associated with views of nature which is based on psychological mechanisms. Exposure to sunlight has in addition a physiological impact on pain perception; being exposed to sunlight increases the level of serotonin in human body and the higher level of this neurotransmitter inhibit pain pathways (Walch, J.M. et al. 2005).

Both mechanism show the importance of windows in spaces where patients recover from their surgery or suffer from pain. This is also an issue that needs to be addressed in other areas for examination and treatment where pain is an issue, because natural views and exposure to sunlight should be available in these patient care and treatment areas as well.

2.2 POSITIVE EXPERIENCE / SATISFIED OCCUPANTS

Connections to the outside such as daylight or windows with a view out have a positive impact on humans. The biophilia hypothesis is one explanation and is supported by numerous studies linking access to nature to positive health outcomes in healthcare facilities. The biophilia theory, developed by E.O. Wilson in 1984, states that humans, as a extension from evolution, have a partially genetic tendency to respond positively to nature (Wilson, E.O., 1984). Integrating nature in the building environment is linked to positive health outcomes and positive experience and satisfied occupants as suggested by numerous studies. Indeed, daylight in a workplace is the most preferred source of lighting. An internet survey of staff working in a newly constructed facility found that access to daylight was the most important improvement on work life. (Mrochzek et al., 2005). Nurses being exposed to daylight for more than 3 hours during their work showed less perceived stress, higher job satisfaction and lower intention to quit in comparison to nurses with a daylight exposure less than 3 hours per day. (Alimoglu, M. K., & Donmez, L.,2005). Thus, an improved environment with ample access to daylight can increase staff satisfaction and potentially reduce staff related costs associated with turnovers.

Regarding patient satisfaction, studies have predicted that if environmental satisfaction is high it is more likely that overall satisfaction in hospitals will be also high (Harris et al., 2002). Therefore an aesthetically pleasant environment with ample connections for patients and visitor to nature and daylight, is important. In public spaces, spaces

INCREASE SATISFACTION

DESIGN APPLICATION:
Primary work stations, public spaces as waiting or cafeteria
RELATES TO GUIDELINE:
perforated building footprint, narrow building footprint, courtyards in inpatient units, skylights and clerestories in inpatient staff and public areas

Figure 22: Increasing satisfaction and its design applications.

Figure 23: Design proposal for daylighting the basement, White Architects, Sweden.

Figure 24: Operation theater with windows, Insight Clinic, Albury, Australiaw

close to windows are preferred as seat selection studies illustrate,. These studies conclude that people prefer and assign more value to seating location near windows and views (Kim, J.J. & Wineman, J., 2005).

However, daylight can also compromise occupants comfort, if it penetrates the interior without control, which can result in unwanted heat gain, glare and eyestrains in certain orientations at certain times of the day or year. Thus, the distribution of daylight needs to be controlled and redirect by exterior and interior shading devices, low emission-glazing and by designing windows with distinct design features for lower view-windows and upper daylight windows.

2.3 PRODUCTIVITY

Generally, the direct linkage between access to daylight and productivity is difficult to examine, due to complex influences, resulting in different human performance impacted by the circadian rhythm, the visual system and other sensory systems.

A basis for numerous studies is the interaction between workers mood and performance. But it is still not clear if mood improves performance or if improved performance itself increases mood. In northern latitudes the mood of workers are lower during winter months than during summer and they are more likely to develop the symptoms of seasonal affective disorder, caused by a disruption of the circadian rhythm due to shorter days and thus shorter availability of daylight. This difference in mood and symptoms was not found in locations closer to the equator (Kueller et al. 2006).

Bright light levels during the day, distributed through a window, can help to improve office workers productivity during winter months in northern latitudes. Their counterparts in windowless offices with lower illumination levels spent more time on computer tasks, more time talking on the phone and to coworkers. (Figuerio et al. 2002). In this study people in interior offices were less productive than people in windowed offices during winter months. They found a 6 percent improvement in call centers average handling time for workers with the highest rated view, as compared with workers with no view at all. (Heschong et al., 2003)

IMPROVE PERFORMANCE

DESIGN APPLICATION:
All staff working areas.
RELATES TO GUIDELINE:
perforated building footprint, narrow building footprint, courtyards in inpatient units, skylights and clerestories in patient, staff and public areas.

Figure 25: Improving performance and its design applications.

Having a window with a view to the outdoors and daylight can also increase concentration. This is the result of the study by the Heschong Group in 2003. They compared tests performance data from 21,000 students. Students in classrooms with the most daylighting progressed 80 percent faster on math tests and 26 percent faster on reading test than those in classrooms with less daylight. The comparison also indicates that students in rooms with the largest window area progressed 15 percent faster in math and 23 percent faster in reading, and in classrooms with skylight and diffuse daylight distribution students performed 19 percent faster than students in rooms without (Heschong et al., 2003).

2.4 SAFETY

High Illumination levels reduce dispensing errors. A study by Buchanan et al. in 1991 concluded an association between illumination levels and prescription error rate. In that study the overall prescription error rate was significant lower at a high illumination rate (2.6% with 146 foot-candles) than with a lower illumination level (3.8% with a 45 foot-candles). While this study used an artificial light source, daylight is an excellent source of bright light levels at no operational costs.

Several studies suggested that daylight may have positive impacts on lowering perceived stress levels of staff, increases concentration, improves visual performance at staff work stations, reduces depression, regulates circadian rhythm and improves quality of sleep (see Regulate Circadian Rhythm, Reduce Depression, Reduce Stress, Improve Performance and Increase Concentration). High stress levels, decreased concentration, fatigue and low visual performance could result in lower performance and could be a risk for medical errors.

REDUCE MEDICAL ERRORS

DESIGN APPLICATION:
All staff working areas.
RELATES TO GUIDELINE:
perforated building footprint,
narrow building footprint,
courtyards in inpatient units,
skylights and clerestories in
inpatient staff and public areas.

Figure 26: Reducing medical errors and its design applications.

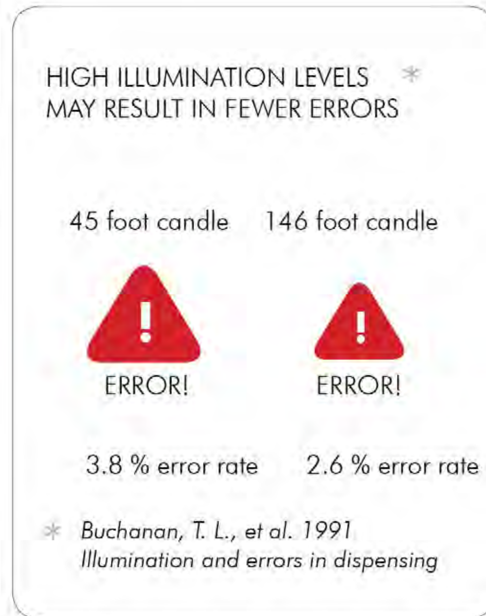


Figure 27: Impact of illumination levels on error rates in dispensing.

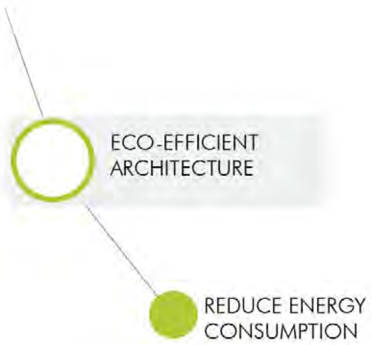


Figure 28: Linkage between eco-efficiency and energy consumption.

3 DAYLIGHT AND ECO-EFFICIENT ARCHITECTURE

The mission of hospitals is inherently to provide a healthy environment and improve healthcare, and must also consider the health of the natural environment for future generations. Being challenged by strong evidence of carbon driven climate change and thus the need to reduce greenhouse gas emission and energy consumption, building sustainable healthcare facilities should not be voluntary. It should be mandatory and an imperative for world-class hospitals.

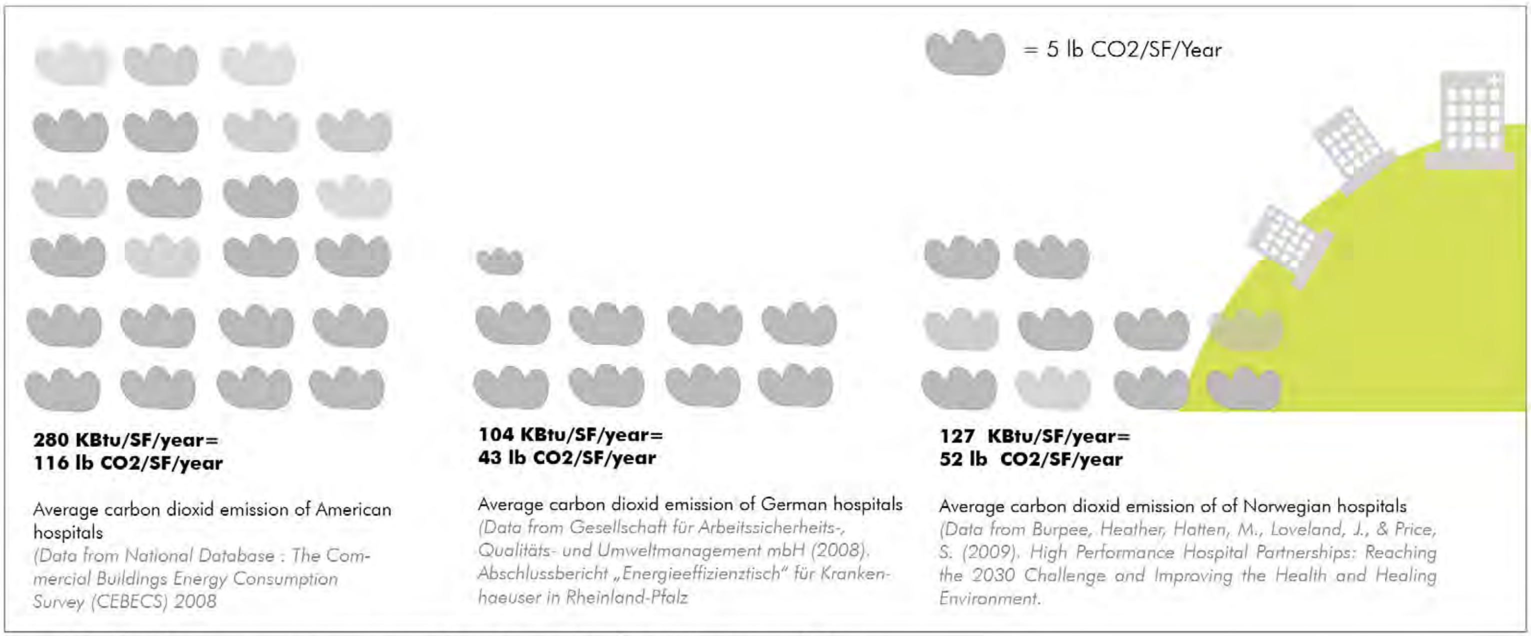


Figure 29: Greenhouse gas emission per square foot in hospitals in the US, Germany and Norway.

American hospitals are among the most intensive energy users for this building type worldwide. For instance, the average carbon dioxide emission of American hospitals was 280 KBtu/SF in 2008. In comparison, the average CO2 emission of German hospitals was 104 KBtu/SF and Norwegian hospitals produced 127KBtu/ SF (Figure 29). These data illustrate the importance and potential of American hospitals to reduce their energy consumption and thus, greenhouse gas emission. Other countries have focused on increasing building energy efficiency for far longer than the US and provide lessons on how to reduce energy consumption and at the same time provide highly efficient and healing environments.

The fundamentals of this idea are expressed in the 2002 ASHE Green Healthcare Construction Guidance:

> "1. Protect the immediate health of building occupants.
> 2. Protect the health of the surrounding local community.
> 3. Protect the health of the global community and natural resources."
> (Guenther, R. & Vittori, G., 2008)

One sustainable development which supports the above, is the eco-efficient movement. This means "creating more goods and services with ever less use of resources, waste and pollution." (http://wbcsd.org) Future healthcare facilities with better outcomes will need to use less energy and resources than hospitals today, by using different design strategies, such as reformulation of their HVAC systems, solar energy, daylighting, ground coupled heat pump etc. for reduction of their CO_2 footprint throughout their development and life cycle. Their design and operation must become more efficient.

An integrated design approach where climate and local natural forces are considered during the design process is essential for an eco-efficient architecture. For instance, natural existing conditions such as wind directions or the path and the intensity of sunlight influences the building form and orientation. These strategies can be used for illumination (daylighting), heating, cooling or delivery of fresh air by cross ventilation or stack-effect ventilation. Considering and using these conditions provides the potential to substantially reduce the energy consumption and greenhouse gas emission of a building.

3.1 GLOBAL HEALTH IMPACT

In the U.S., the building sector is responsible for about 50% of all energy consumption. Among building types, hospitals are the second most intensive energy user within the building sector, just behind fast food restaurants. (US Department of Energy) Hospitals are responsible for over 4% of all energy, used in the U.S., contributing significantly to total building energy use in the US and illustrating the importance of potential energy savings to reduce greenhouse gas emission.

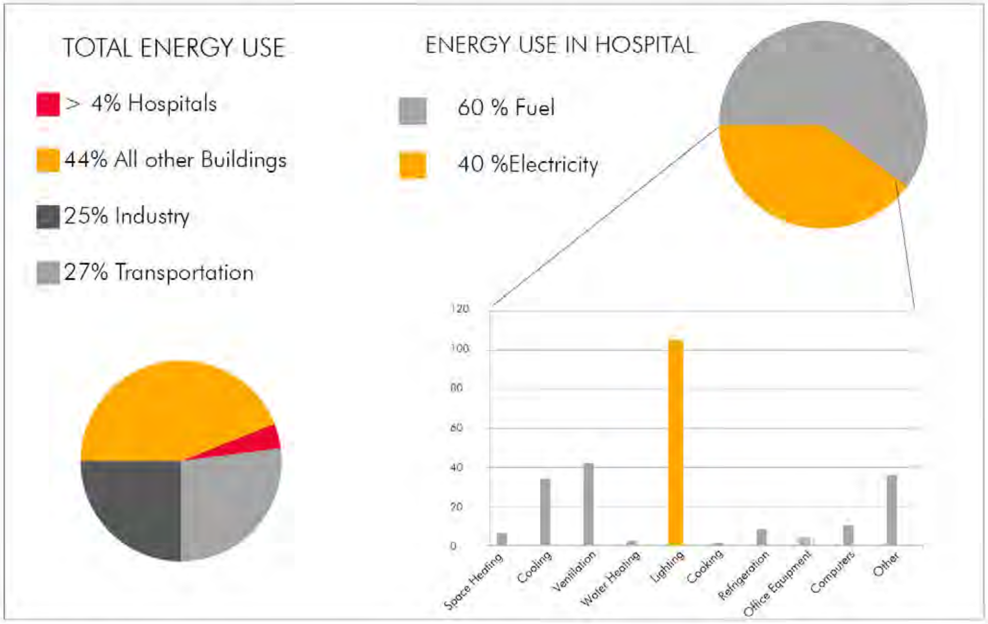


Figure 30: Diagram illustrating energy use in hospitals and electricity consumption (Btu) by end use for healthcare buildings in the US in 2003.

Driven by the increased concerns about carbon driven climate change, the architecture community decided to achieve a substantially reduction of energy consumption associated with buildings. Its targets are summarized in the "Challenge 2030 Initiative (http://architecture2030.org). In July 2010, 73% of the 30 largest architecture/engineering firms in the U.S. have adopted and are implementing the Challenge 2030 (40% of all architecture/engineering firms in the U.S.). The target of the 2030 challenges states that future buildings shall be designed to reduce their energy consumption to 50% of the current local average of this building type by 2030 by implementing:

> "1) appropriate planning and passive design strategies, then 2) improved material selection, building envelope design, more efficient lighting, equipment, and appliances, and finally by 3) on-site and community-scale renewable energy technologies." (http://architecture2030.org/the_solution/solution_energy)

International examples show that a reduction by 60% percent of energy consumption is possible. For instance, some hospitals in northern Europe, consume only 30% to 50% of the energy of their American counterparts (Burpee, H. & Loveland, J., 2010). Investigations of innovative energy concepts at some of these hospitals, for example in Scandinavia, indicate the difference in practices, codes and culture. Among the key concepts in energy management in other countries are daylighting and natural ventilation. Understanding the global best practices of integrated design concepts brings application potential to the US. Respectively Scandinavia is located in a climate zone which can be, due to the size of the US, only compared to the northern part of the US. However the integrated design approach “form follows climate” is the same, even when adapted to local climate conditions in more southern parts of the US.

European hospital typologies employ narrow building footprints, which are decentralized into centers and clustered around each other. In contrast American hospitals often compress all these into one thick building as a inpatient tower on a diagnostic and treatment platform. Another common form is the linking of a thick diagnostic and treatment block to either an inpatient tower and/or series of wings, usually along a connecting spine. This unbundled typology segregates diagnostic and treatment areas from inpatient areas. This organization in theory allows the shorter travel distances between different departments, however isolating many clinical and support work spaces from nature, especially in diagnostic and treatment departments, decreases flexibility and creates thick building footprints with minimal building perimeter and limited access to daylight and fresh air.

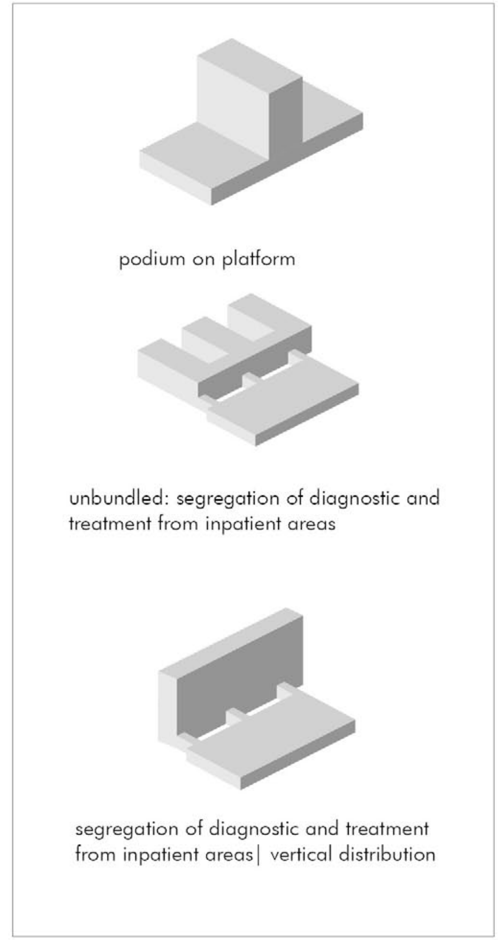


Figure 31: Common hospital typologies used in the US.

3.2 DAYLIGHT AND ENERGY CONSUMPTION

An eco-efficient hospital optimizes the use of daylighting to lower energy consumption. The following statements, concluded from the literature review can be made:

Daylighting lowers energy consumption: Daylighting (when employed properly) lowers energy consumption if included into the planning process to reduce artificial lighting use and if lights are dimmed or switched off by automatic controls when required illumination level is provided by daylight (NBI/ USGBC Report 2008). Results of studies, analyzing energy consumption in offices varied between 27% up to 70% energy reduction- when automatic light control is used (Roisin, B., et al.2008, Reinhart, C. F., 2002, and Newsham, G.R., 1994).

Daylighting can reduce cooling loads: Daylighting (if designed properly) reduces cooling loads due to reduced use of artificial light sources (Burpee and Loveland 2010). Most hospitals, even in cold seasons are constantly in cooling status because of internal heat loads resulting from lighting, equipment and people (Burpee and Loveland 2010).

An appropriate shading and re-direction system can reduce cooling loads: If solar heat gain is not addressed in the building design it will increase cooling loads and operational cost dramatically. Effective shading systems blocks and re-direct sunlight to avoid internal heat gain and are specific to the building's geographical location, the specific site orientation and context conditions and its local climate. Each building location and orientation of exposed facades requires individual shading systems designed to address ever changing sun angles and intensity during the day and the season.

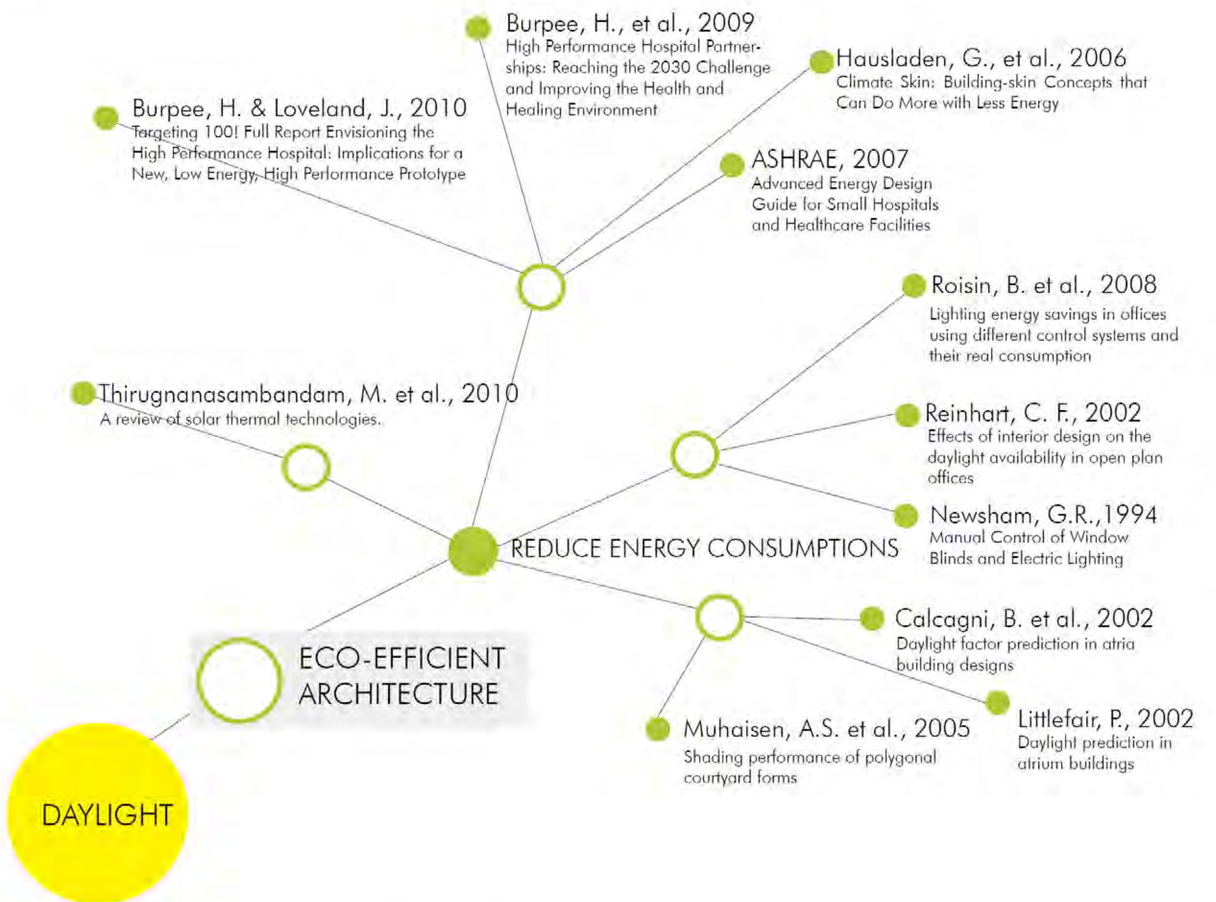


Figure 32: Map linking supportive literature to energy savings

Figure 33: Daylight area of Dell Children's Hospital in comparison with its square root base.

3.3 ENVIRONMENTAL RESPONSIBILITY: LEED AND GGHC ACCREDITATION

An accreditation program can motivate and help to develop a building with an sustainable approach. The best-know building accreditation program in the US is the LEED (Leadership in Energy and Environmental Design) certification. The accreditation is voluntary, and in order to acquire it, it must be proven that the building meets certain environmental standards for sustainability, efficiency and indoor environmental quality. In the most current LEED NC version 2.2. only two out of 57 credits address daylighting and views to the outdoors. The first credit addresses daylighting and requires a daylight factor of minimum two percent for at least 75 percent of the floor space (Credit 8.1: Daylight and views) and the other credit addresses connection through views to the outside and thus requires a direct line of sight to vision glazing from 90 percent of the floor space (Credit 8.2).

However, two daylighting credits out of 57credits are certainly not enough to encourage health care providers, architects and investors, to integrate daylighting and direct views within their building. Furthermore the daylighting credits, especially the daylight factor, is difficult to calculate and achieve during the design process of large healthcare projects. (Pradinuk, R., 2008). One example is the Dell Children's Center in Austin, Texas. The hospital has an articulated building footprint and incorporates several courtyards to increase the perimeter wall (Figure 33). As a result, 36 percent of the building space is located within the daylight zone. Yet, even awarded as the first hospital in the US with the LEED Platinum certification, the project did not fulfill the requirement to earn the daylighting credits. Regarding daylighting and views, these difficulties for the design of large healthcare project, were addressed for the development of the LEED for Healthcare. It just passed member ballot on November 16th, 2010 with a 87% approval rate. The basis for its development was a collaboration with the Green Guide for Healthcare.

The Green Guide of Healthcare (GGHC) v 2.2 is a self-certifying environmental design toolkit with a greater emphasize on daylighting: 5 points can be achieved with daylighting, three more than with the LEED accreditation. Two of these points address daylighting issues in inpatient units. One point is achieved through access to daylight in patient rooms and the other point is achieved by providing access to daylight in other areas on the unit whereby the visual connection to the outside has to be provided from 75% of regularly occupied staff work spaces and non- inpatient rooms. Another point counts for a visual connection from 90% instead of 75% of regularly occupied staff work spaces. The greatest number of points can be achieved by increasing daylight areas in Diagnostic & Treatment areas by means of articulated building plan forms or penetrations such as courtyards and skylights into larger blocks of space. Criteria for achieving points hereby is the percent of total floor area within 15' of the building's perimeter. Then, this area will be compared with the area within 15' of hypothetical perimeter formed by a square of the actual building floor area. Based on the performance up to three points can be achieved. If the daylight area of a project is over 6 percent of its square root base the building would qualify for one point. A 12% increase of daylight area qualifies for two point and the

INPATIENT AREAS

in inpatient rooms +
75% of staff area = 2 points
90% of staff area = additional point

DIAGNOSTIC & TREATMENT

within 15' of perimeter
6 % above squarerootbase= 1 point
12% above= 2 points
18% above= 3 points

Figure 34: Daylighting points, GGHC.

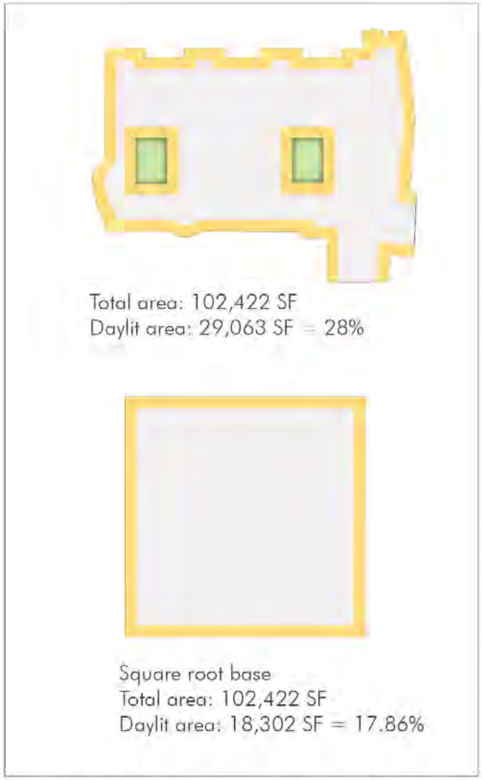


Figure 35: GGHC perimeter calculation for the diagnostic and treatment department of the Palomar Pomerado Health Medical Center, CA.

maximal amount of points can be achieved with a daylight area 18 percent larger than its square root base (Figure 34). The simple calculation process is illustrated in Figure 35 and can be easily determined in an early stage of a project.

For instance, the daylit area of the diagnostic and treatment department of the Palomar Pomerado Health Medical Center is 59% larger than the daylit area of the square root base. The building is perforated with two enclosed courtyards, large enough to qualify as "outside" along main circulation corridors at staff work points or department's boundaries (Figure 35).

The LEED criteria for Healthcare includes 5 credits out of 100 for daylighting and views to nature in their accreditation. Similar to the GGHC one credits addresses views to the outside, but the distance to the window providing the view must not exceed 20 feet. Two points relate to the non-inpatient areas and their percentage of daylit areas along 15 feet of perimeter wall and two credits can be achieved through daylighting. New is that these credits are only achieved if the daylighting is combined with a responsive control system, dimming or switching of artificial lighting if required illumination level are achieved by daylight. This supplement to that credit ensures that energy savings can be in fact be achieved.

4 DAYLIGHT AND HEALTHCARE ARCHITECTURE

Hospitals in the US are typically build with thick building footprints in large part due to the desire to minimize travel distances within and between departments which results in limited availability of daylight in core areas. This was not always the case. Daylight was an important design driver for hospital architecture at the end of the 19th century and contrary to the development in the US, most hospitals in Europe are still laid out with narrow wings and articulated floor plans to provide occupants with almost universal access to daylight, views to nature and natural ventilation.

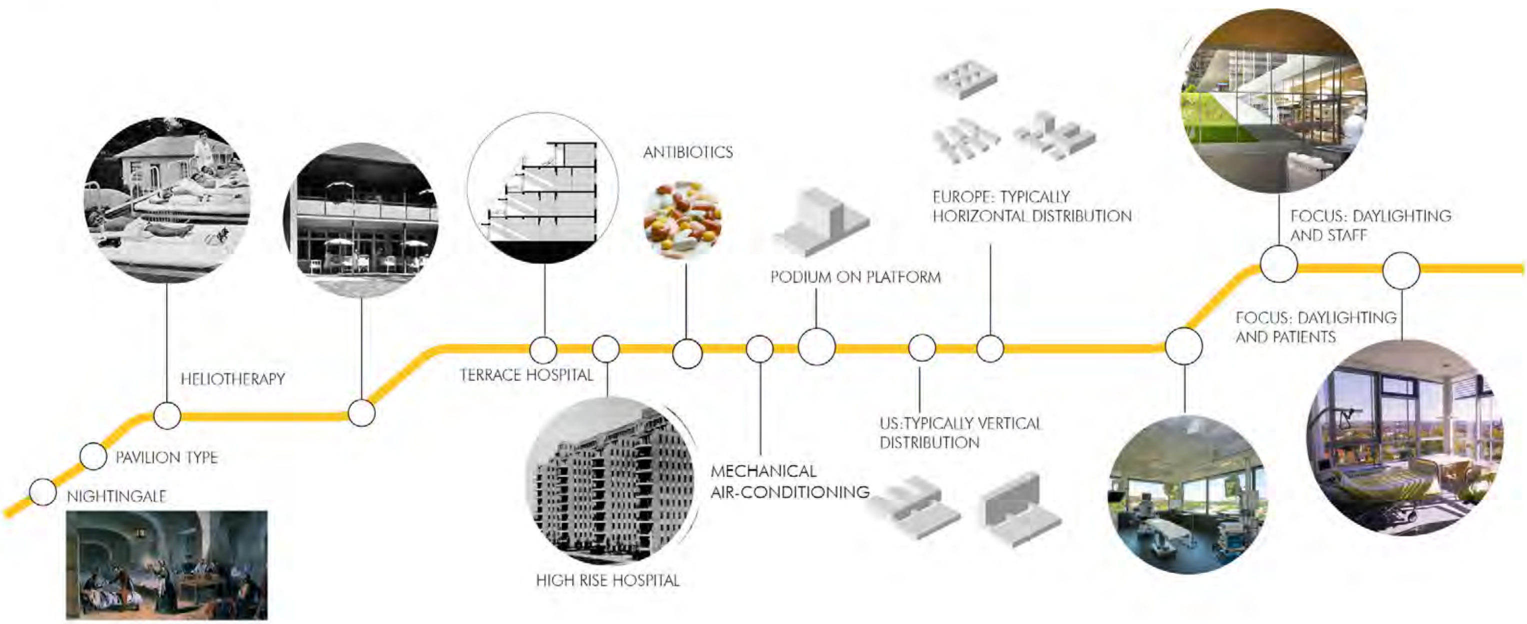


Figure 36: Overview: daylight and healthcare architecture.

4.1 THE HISTORY OF HELIOTHERAPY AND ITS ARCHITECTURAL RESPONSE


Figure 37: Outdoor veranda for Heliotherapy. King's Daughters Home (1918-1920) Memphis, Tennessee.


Figure 38: Patient on outdoor terrace around 1930, St. Thomas' Hospital, London

> "It may seem a strange principle to enunciate as the very first requirement in a Hospital that it should do the sick no harm. It is quite necessary nevertheless to lay down such a principle." Florence Nightingale (1820-1910).

Florence Nightingale, an English nurse during the crimean war who became famous for her pioneering work in nursing, recognized the importance of the environment on the healing process and survival rates. . She concluded that crowed, dark and poorly ventilated facilities had much higher mortality rates than well-lit and well-ventilated facilities. Her publications, "Notes on Nursing" and "Notes on Hospitals" at the end of the 19th century influenced the building design to promote healing, including design strategies as universal access to daylight and fresh-air. This movement was supported by the discovery that hygiene is crucial against the spread of infection in hospitals and to promote healing. Antibiotics were not yet available and not developed till the late1930s. One strategy for improved hygiene was effective ventilation and the availability of daylight with its antibacterial effect being the most effective and sometimes only available treatment method for some diseases as tuberculosis and wound infection. A typical hospital typology during that time was the pavilion form with its narrow wings and large openings in the facade to force natural ventilation and the penetration of daylight. Patients suffering from tuberculosis in particular were treated with light therapy, or also called Heliotherapy. Heliotherapy was first developed by the Danish surgeon Niels Finsen who received the Nobel Prize for his research in 1903. The therapy was grounded on the antibacterial effect of UV-light (which is part of the sunlight spectrum) on infections. Direct sunlight therefore speeds the healing process of infected wounds. To integrate Heliotherapy as a treatment method in clinical settings, special sanatoriums were built which required specific architectural design features, including balconies and roof or garden terraces.

One example of a humanistic approach to the design of a sanatorium is Alvar Aaltos' Paimio in Finland, built between 1929 and 1933. The sanatorium is located in a rural setting, surrounded by hills of forest (Figure 39). Aalto constructed the building to maximize sunlight penetration and sun-harvesting, especially important for that particular geographical location, far north, straddling the Arctic circle. The building is separated into different wards, each addressing the unique settings of the landscape. The large wing offers space for 24 patients on each floor in two-bed rooms along a single-loaded corridor, all facing south/southeast. For heliotherapy, each floor has a rest terraces on its western end, and on top of the wing, a large terrace and a roof garden provides space for sunbathing (Figure 40). The construction of the window in patient rooms is asymmetrical to maximize morning sun penetration and minimize sun penetration during the afternoon. External blinds are used to control direct sunlight and glare. Two double glazed windows are arranged behind, each in a cast iron frame. This construction allows vertical ventilation when open and avoids draft. Between these two windows, a heating element was placed to warm the incoming air (Figure 41). The artificial light source is located behind the patient's head at the edge of the wall and ceiling to avoid the glare of a light source and to

Figure 39: Paimio sanatorium, Finland and its rural setting.

Figure 40: Roof terrace for sunbathing, Paimio, Finland.

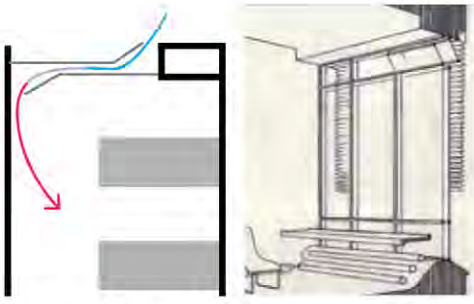


Figure 41: Patient room with operable windows.

provide diffuse lighting for patient's range of vision. In public spaces, as the dining hall, work and patient recreation rooms, all facing south, sloped ceilings maximize sun penetration because of larger openings towards the south. A bright yellow color linoleum as floor material support the perception of a warm atmosphere by reflecting the light with a warm light spectrum with emphasize on the yellow/red spectrum.

Over the years, Paimio has been extended, but it is still used as a healthcare facility. However, Tuberculosis treatment is no longer its focus since the invention of antibiotics in the 1930s and the treatment by sun and air became unnecessary.

Heliotherapy was not only used for sanatoriums and tuberculosis treatment clinics, the promising results in tuberculosis treatment led to the thought that other patients could profit from climate therapy, too. Terraced buildings were often employed in hospital design during the transitional phase after the pavilion typology lost its main dominance for hospital buildings in early 20th century and before the development of the high rise hospital after 1945.

The Terrace hospital type was an approach to integrate climate therapy in multi-floor general hospitals. The goal of a stepped back building was to optimize natural ventilation and maximize exposure to sun and fresh air to reduce the spread of infection and to hasten the healing process of patients with infected wounds. The buildings were usually not higher than 4-5 floors and each floor was stepped back by one terrace depth and provided enough space where patients could be moved outside during temperate weather in their bed. Its south facing wards had wide openings often with direct connections to terraces, porches, and green spaces to maximizing patients exposure to fresh air and daylight. Patient beds in these kind of wards were facing towards the outside (Figure 44) whereas in earlier wards patients were facing towards the interior.

Figure 43: Patients beds on balconies, facing south.

Figure 44: Patients facing the outside, inpatient ward in Zwickau, Germany.

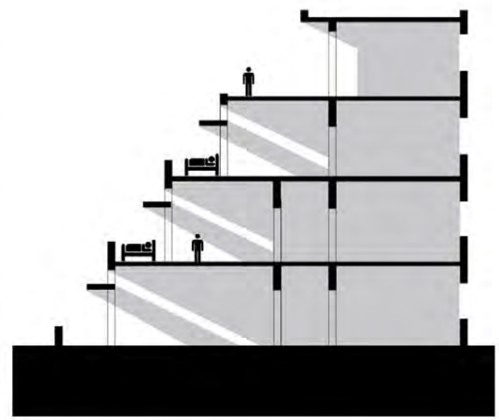


Figure 42: Terrace typology as hospital.

4.2 THE DISCONNECTION FROM NATURE: US HOSPITALS AFTER 1945

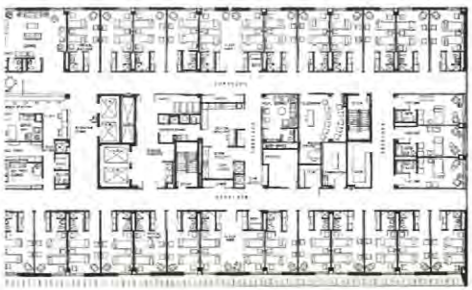


Figure 45: Racetrack plan 1965, Archbishop Bergan Mercy Hospital, Omaha, Nebraska.

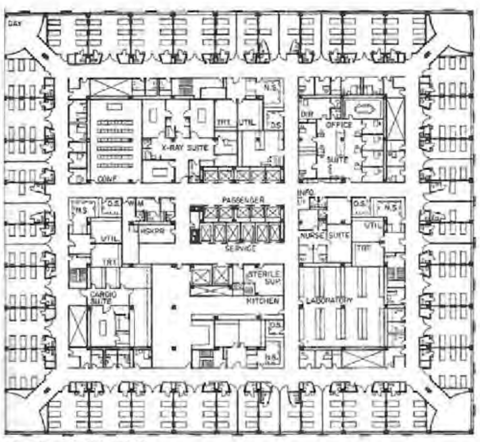


Figure 46: Bellevue Hospital, New York City 1974

Until the early 20th century daylight was the main source of lighting in hospitals, mainly because clean and safe electrical lighting was either not available or not widely available. By the mid-20th century the development of florescent light and air-conditioning and the availability of relatively low cost energy made new thicker building shapes feasible. It became possible to design rooms without connections to the exterior by mechanically generating and delivering adequate light and air. Former naturally occurring changes of light and air became completely obsolete. In the United States daylight lost its dominant role in healthcare architecture during the Hill-Burton era when thousands of new hospitals were built, based on Hill-Burton´s standards of preset floor plans, room arrangements and minimum standards for diagnostic and treatment departments. Functionalism and efficiency envisioned optimized travel distances, as well as new medical technology and its rising demands for controlled thermal and light environments and ever expanding space requirements, resulted in deep planned building shapes including the rectangular racetrack and the block plan. These concepts optimized staff and patient movement by integration of a core support zone. However, the change from narrow wings and pavilions architecture to deep plan structure resulted in a disconnection from daylight and natural ventilation. With this evolution occupants, both patients and staff, became disconnected from nature and became isolated from natural conditions.

Most other developed countries in the world- those with advanced and comparable healthcare delivery to that found in the United States- still design and build healthcare facilities with extensive access to and requirements for daylight, views and natural ventilation. This includes many countries with better health status and health outcomes than in the US. Hospitals in most European countries are required to have narrower building configurations and operable windows that enable them to have widespread access to daylight and utilize natural ventilation when exterior weather conditions permit and interior needs can be met without mechanical conditioning. Hospitals in these countries are typically laid out with narrow wings and/or contain courtyards and atria to provide occupants with almost universal access to daylight, views to nature and natural ventilation (Figure 47: Hospital Agatharied, Germany).

Figure 47: Hospital with perforated and articulated building footprint.

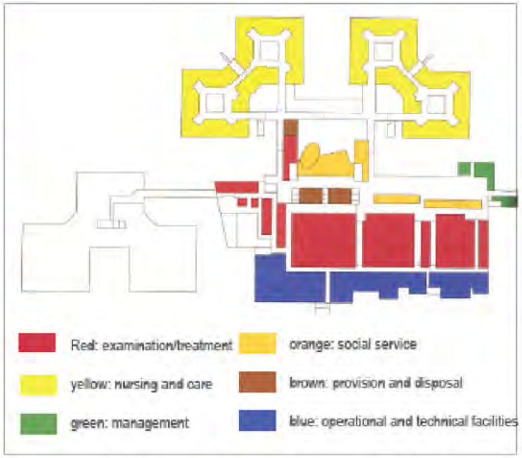


Figure 48: Departmental plan, Community Hospital Agatharied, Germany.

Figure 49: Central courtyard in Inpatient Unit provides connections to the outside from primary work station Community Hospital Agatharied, Germany.

These examples from around the world and an emerging number of facilities in the US are demonstrating that hospitals can be functionally efficient and effective places for patient care, environmentally responsible and healthier for all their occupants when they are designed to optimize access to daylight and views to nature.

Typically hospital typologies such as the street typology, the terrace typology, the perforated block or the campus plan (Figure 50) promoting these connections in patient care, work spaces and public areas are based on narrow building footprints or articulated and penetrated plan forms. In some countries in Europe, for instance in Germany, the connection to the outside and providing a view, in primary staff working areas is mandatory by law due to its necessity for a safe and healthy environments.

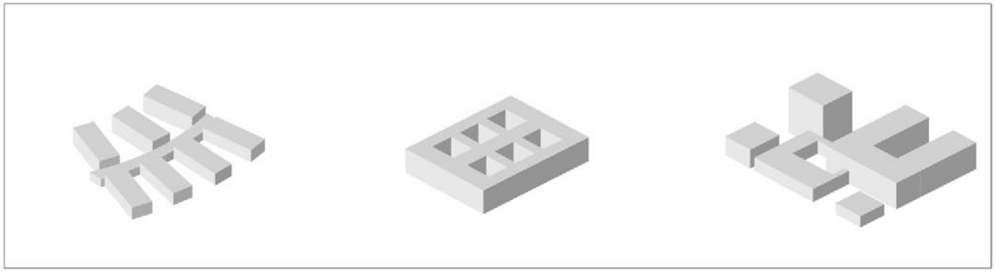


Figure 50: Typical hospital typologies used in Europe: street typology, perforated building block and campus plan.

4.3 THE RECONNECTION: CURRENT AND FUTURE DAYLIGHT LEGISLATIONS

Daylight Measurements: There are different ways to express daylighting in numbers to make daylighting design calculable, predictable and comparable. Potential daylight measurements used for codes, requirements and guidelines considerations are either based on window size and their window-to-floor area ratio or on the quantity of illumination which, for instance, can be calculated by determination of the daylight factor: Daylight factor (D) = Illumination level inside (Ep) divided by illumination level outside (Ea) times 100 (Figure 51). This factor compares the illumination level on a horizontal surface inside a room with the illumination level of the outside, measured on the ground under overcast conditions. Another way to determine the quantity of light is based on required illumination levels for different tasks performed in that space. This is not exclusively descriptive for daylighting but also for artificial lights. However, the ratio of the glazing to the floor area was developed based on required illumination level for certain tasks. For instance, a ratio of 1/5 glazing to floor area (required for critical tasks), achieved on 85% of all days during the year, yields a required illumination level of at least 500 lux on horizontal working areas close to the window (Assumption of German DGUV). The perimeter length and thus the percentage of daylight area within 15 feet of the outside wall is often used in building accreditation as in the Green Guide for Healthcare or the LEED for Healthcare to encourage accessibility for daylight and visual connections to the outside.

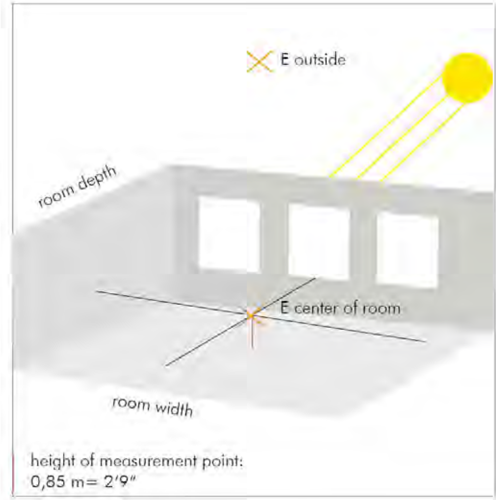


Figure 51: Calculation of daylight factor (DF).

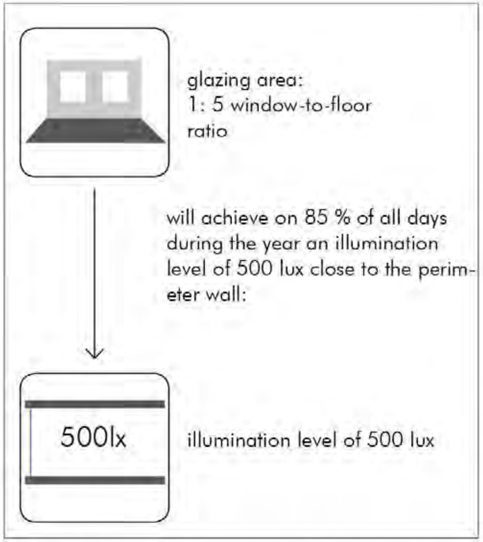


Figure 52: Size of glazing area and its relationship to interior illumination levels.

In the U.S., no code exists making the access to daylight or views to the outdoors in buildings mandatory, except for patient rooms. The Guidelines for Design and Construction of Health Care Facilities, 2010 edition, which is used in 42 states as a code or reference standard to develop state specific codes, only requires the consideration of natural light and views to the outdoors in the design of the physical environment. This could mean anything and doesn't specify the availability of daylight in buildings, neither for what kind of spaces access of natural light is appropriate, nor how much daylight is appropriate:

> " A1.2-2.2.2.5 Physical Environment
> Light and views. Use and availability of natural light, illumination, and views shall be considered in the design of the physical environment."
> (The Facility Guidelines Institute: Guidelines for Design and Construction of Health Care Facilities, 2010 edition. p.14)

However in the most current edition 2010 of the "Guidelines", an appendix was attached to the codes, suggesting specified strategies regarding the physical environment including light and views:

> " A1.2-2.2.2.5 (1) Light and views.
> Natural light, views of nature, and access to the outdoors should be considered in the design of the physical environment wherever possible.
> a. Access to natural light should be provided no further than 50 feet

from any patient activity area, visitor space, or staff working area. To the highest extent possible, the source of such natural light should also provide opportunities for exterior views.

b. Siting and organization of the building should respond to and prioritize unique natural views and other site features

c. Access to natural light should be achieved without going into private spaces. (i.e. staff should not have to enter a patient/ resident room to have access to natural light). Example include windows at the end of corridors, skylights into deep areas of the building in highly trafficked areas, transoms and door sidelights. (.......)

(The Facility Guidelines Institute: Guidelines for Design and Construction of Health Care Facilities, 2010 edition. p.15)

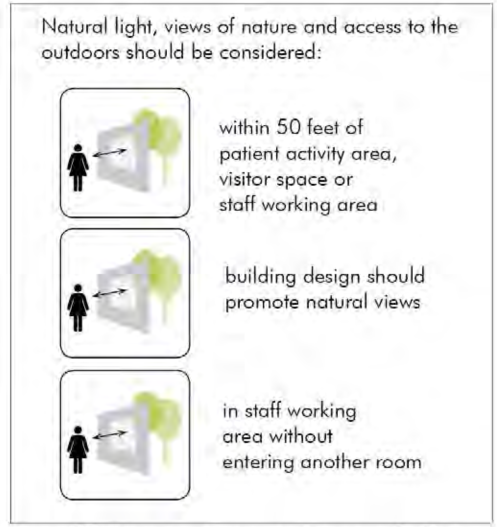


Figure 53: Recommendations in the appendix "light and views" FGI Guidelines, 2010 edition.

In the future, more prescriptive requirements regarding natural lighting and views might be developed and added to the recommendation. The FGI Guidelines announced in the forward of the current edition that the use of natural lighting and window size are one of the issues being studied for the 2014 edition and thus are currently under consideration. This topic belongs to the group of subjects, according to the Facilities Guidelines Institute:"...playing a vital role in health facility design and construction..."(The Facility Guidelines Institute: Guidelines for Design and Construction of Health Care Facilities, 2010 edition. p.xxvii (Major Additions and Revisions))

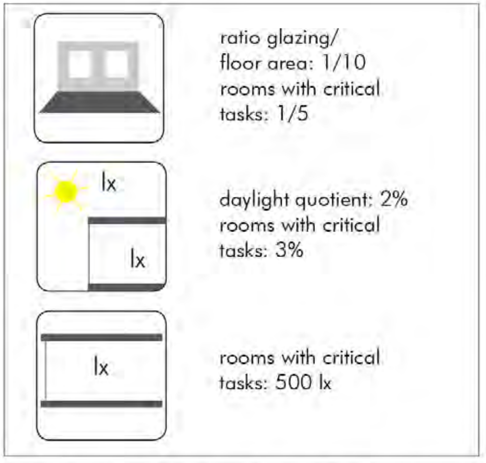


Figure 54: Example of specific daylight legislation: regulations for daylighting in offices in Germany.

In other parts of the world, especially in Europe, codes and guidelines are more specific regarding daylighting in public building such as schools, offices, commercial buildings and hospitals. One example is Germany: According to the codes and regulations of the German Social Accident Insurance (DGUV), access to daylight for workplaces shall be considered to promote health and safety. The DGUV requires a ratio of light transmitted surface (i.e. windows, doors, walls and skylight) to the floor area greater than 1/10. For rooms with critical tasks performance, a window-to floor ratio of 1/5 is required for sidelighting and for toplighting a ratio of 1:6 to achieve an illumination level of 500 lux or a daylight factor of 3%. A 2% daylight factor is recommended for rooms with normal tasks performance.

4.4 BEST PRACTICES: DAYLIGHT HOSPITALS AROUND THE WORLD

It is critical to look outside the US for current guidance and best practices for the optimization of daylight in hospitals and healthcare facilities. Different building typologies illustrate that a hospital can provide daylight and views to the outside in almost all parts of the building and still provide successful, safe and efficient health care. The chosen hospitals are all located within the temperate zone and illustrate best practices for daylighting, combining comfort, efficiency and as well as aesthetic options. They will be referenced in the guideline section of this thesis and include two examples from the US, four from Europe, one from Japan and one from Australia. The following short introduction will describe the selection process and why the case studies are suitable as best practices.

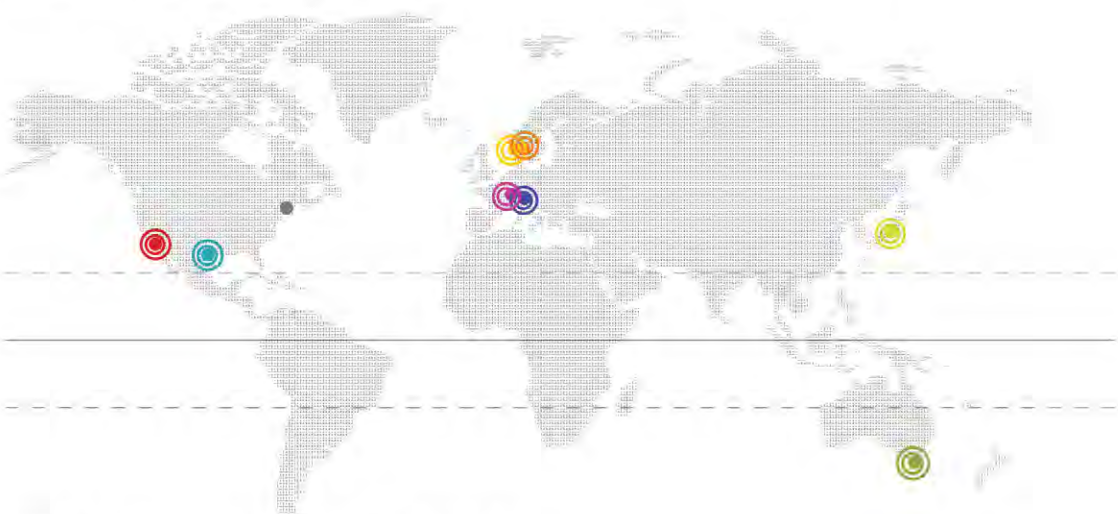


Figure 55: Location of chosen case studies around the world.

		COMPLETION	ARCHITECTS	NATURAL VENTILATION	ENERGY CONSUMPTION	TYPOLOGY
	AKERSHUS Nordbyhagen, Norway	2008	C.F Moeller	yes	estimated 60 KBtu/SF/year	
	RIKSHOSPITALET Oslo, Norway	2001	MedPlan AS	yes	117 KBtu/SF/year	
	PALOMAR POMERADO MEDICAL CENTER, CA, US	2011	Association of CO Architects and Anshen & Allen	no	n/a	
	DELL CHILDRENS HOSPITAL , Austin, Texas	2007	Karlsberger	no	261 KBtu/SF	
	REHAB, Center for Spinal Cord and Brain Injuries, Basel, Switzerland	2002	Herzog & de Meuron	yes	n/a	
	KIZ CHILDREN'S CLINIC Innsbruck, Austria	2008	Nickl & Partner Architects	yes	n/a	
	ALFRED HOSPITAL, ICU Melbourne, Australia	2008	Billard Leece Partnership	yes/no	n/a	
	KATTA PUBLIC GENERAL HOSPITAL, Japan	2002	Taro Ashirara Architects/ Hideto Horike& Associates	yes	n/a	

Figure 56: Case studies, their typologies, energy consumption and optional natural ventilation.

Akershus Hospital | Norway | Construction cost per SF: 678

The Akerhus Hospital in Norway was chosen as a case study because of its successful integration of narrow building footprint for the inpatient units and its integration of courtyards for the diagnostic and treatment departments. The hospital, completed in 2008 and built by Arkitektfirmaet C.F Moller, uses the street typology to link all departments together. To provide daylighting and to assist natural ventilation, the main street is built as atria with side openings located at the top. The hospital's annual energy consumption is an estimated 60 KBtu/SF (Burpee, H. & Loveland, J., 2010).

Figure 57: Data, Akershus Hospital.

Rikshospitalet | Norway

Similar to the Akershus Hospital, this hospital is built based on the street-typology. The hospital uses only one third (117 KBtu/SF/year) of the amount of energy used in average American hospitals (280 KBtu/SF/year) (Burpee, H. & Loveland, J., 2010) Its diagnostic & treatment department integrates 60 ft wide courtyards. Narrow building wings for inpatient units are attached to a main connecting street. This connector is build as an atria with side openings at the top to assist natural ventilation

Figure 58: Data, Rikshospitalet.

Figure 59: Data, Palomar Medical Center.

Palomar Pomerado Medical Center | California, US | Construction cost per SF: 549$:

The hospital planned by CO Architects and Anshen+Allen will be the first contemporary hospital in the US integrating two courtyards in the diagnostic and treatment block. These courtyards are located along the main circulation corridors and between diagnostic and treatment departments. The roof of the diagnostic and treatment block will be planted to provide a green roof for patients overlooking the roof. Also, large balconies on each inpatient floor provide physical access to the outside for visitor, staff and patients.

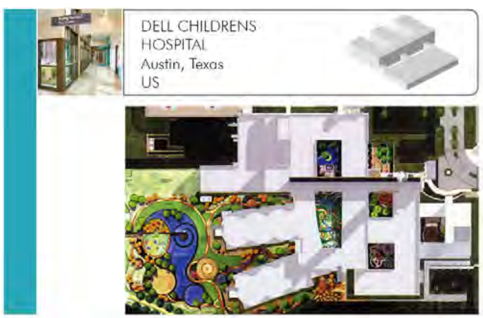


Figure 60: Data, Dell Children's Hospital.

Dell Childrens Hospital | Texas, US | Construction cost per SF: 257$:

This hospital was the first of its kind awarded with the LEED Platinum certification and designed by Karlsberger. The building is articulated and integrates six internal courtyards, some of them used as healing gardens. 90% of all perimeter rooms have a window and 60% of the occupied spaces without medical demand are connected to the outside and 35% of spaces in the diagnostic & treatment department have access to daylight. Most of the areas are located within 32 ft of the building's perimeter. 33% of artificial lighting is connected to an occupancy sensor turning the light off if the area is not occupied. The hospitals annual energy consumption is 261 KBtu/SF.

REHAB Center| Switzerland | Construction cost per SF: 446$:

Connections to nature as part of the healing environment is the main design driver for this rehabilitation center in Switzerland, planned by Herzog de Meuron. The building integrates 9 courtyards in its footprint to increase the perimeter wall. Therefore 65 percent of the space is located in the daylight area within 15 ft of the perimeter wall and 95 percent of all regularly occupied spaces have a connection to the outside. Circular skylights above patient beds provide a view out for paralysed patients.

Figure 61: Data, REHAB.

KIZ CHILDREN'S CLINIC | Austria | Construction cost per SF: 379$:

This case study, designed by Nickl & Partner is used to illustrate the design approach of integrating courtyards in the support zone of an inpatient race-track plan. The 95' wide inpatient unit, 6 stories high, with a support zone of 25' is perforated with several courtyards of 25' x 46' width and length. Examination rooms and doctor's offices are directly attached and fully glazed. Another feature of the inpatient unit is the staff balcony, providing physical access to the outside for staff from the unit's staff break room.

Figure 62: Data, KIZ Children's Hospital.

Figure 63: Data, Alfred Hospital.

Alfred Hospital, ICU | Australia | 9688 sq.-ft. expansion

The intensive Care Unit of the Alfred Hospital in Melbourne is one of the most advanced Intensive Care Units using clerestories to illuminate the core work area. Designed by Billard Leece Partnership and Arup, the concept of very high ceiling above the core supports displacement ventilation and the diffuse distribution of daylight: all clerestories include switchable glass panes to diffuse the incoming light. This kind of glass is also called “smart glass”. When voltage is applied, the glass or glazing changes light transmission properties.

Figure 64: Data, Katta Hospital.

Katta Public General Hospital | Japan

All inpatient rooms of the Katta Hospital, located on the top floor of this 3-story hospital in Japan have direct access to a roof garden. The inpatient wings are located along the north /south axis, providing all patient rooms with direct sunlight. All inpatient areas and most of the public areas have natural ventilation. Skylights in each courtyard introduce daylight into clinical and support areas on lower floors.

5 DAYLIGHTING GUIDELINES

Performance Benchmarks: In order to achieve a successful daylit environment, it is important to know how to achieve the goals. After the literature review and the design review it can be concluded that every objective is linked to certain conditions which can be either measured or expressed. For instance, in order to reduce pain, the orientation and window size of an inpatient room is important: a study from Walch, J.M. et al in 2005 indicated that patients in rooms with bright light levels may

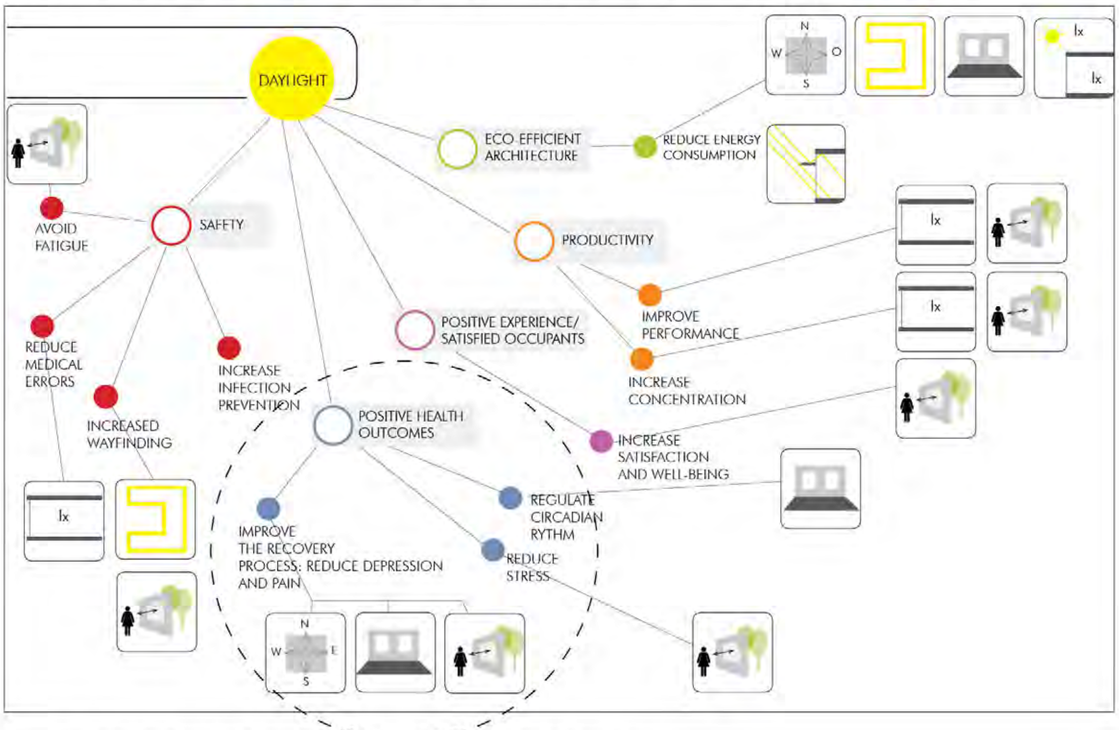


Figure 65: Map linking goals to objectives to performance benchmarks.

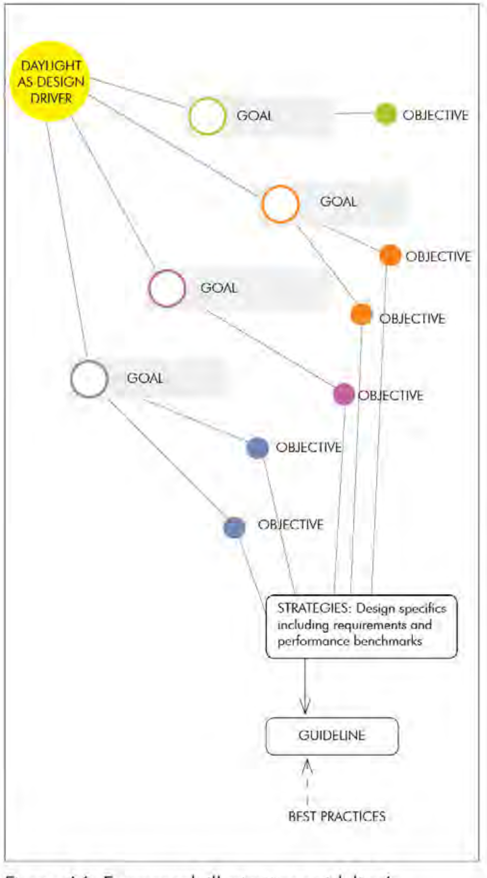


Figure 66: Framework illustrating guideline's principle and development.

experience decreased stress and pain. Another study also showed that the quality of the visual connection to the outside influence the perception of pain: Roger Ulrich's study in 1984 illustrates that patients, overlooking nature scenes perceive significant less pain during their recovery process than patients looking at a brick wall.

The following design guidelines describe ways in which one can incorporate daylighting design ideas (i.e.plan enclosed courtyards) in hospitals within different functional areas (i.e. diagnostic and treatment) to achieve a given daylighting strategy. The design strategy is hereby a plan of action toward achieving a particular goal related to healthcare architecture (Figure 66). The development of each design guidelines also includes the study of best practices of daylit hospitals around the world. These practices are used for illustration in every part of the guidelines. The overview map on the next page illustrates the linkage between each objective and matching performance benchmark. Based on the benchmark taken from literature review, six guidelines are developed, supported by design reviews, and site visits in Australia and the U.S. of best practice case studies. Each guideline addresses a focus area and illustrates the design concepts through data, diagrams of built examples and are based on daylighting principles. These guidelines were developed in part through work on a DoD sponsored research project at Clemson University through NXT and a defense contractor Noblis.

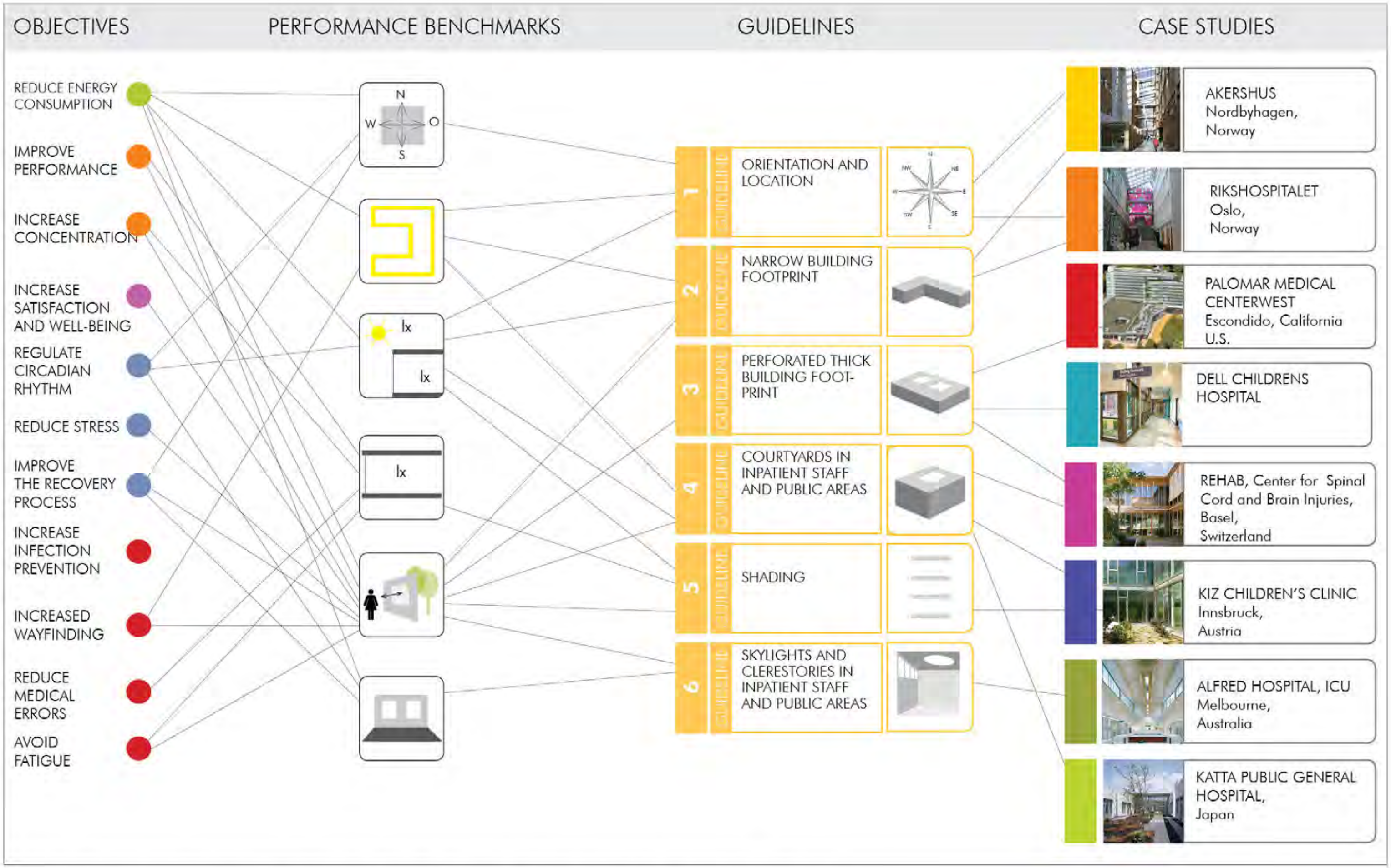


Figure 67: Map illustrating the relationship between the objectives, performance benchmarks, developed guidelines and their case studies.

5.1 PRINCIPLES OF DAYLIGHT ARCHITECTURE

Climate: Daylighting strategies are dependent on geographical location and specific climate conditions. Thus the climate and its characteristics must be analyzed at the beginning of the planning process. This thesis focus on daylighting principles within

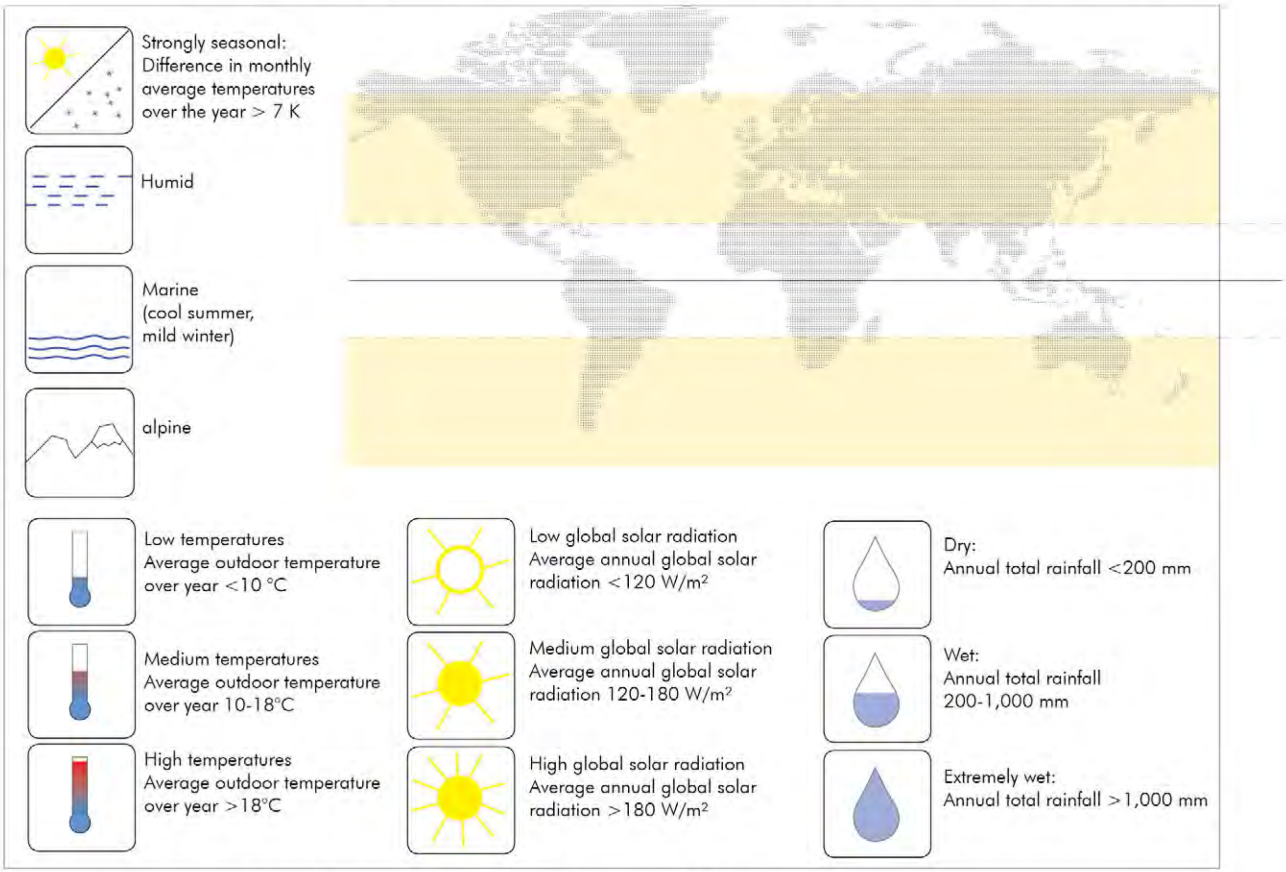


Figure 68: Climate conditions within the temperate climate zone.

the temperate zone. This climate zone is, generally speaking, characterized by seasonal changes and can be sub-categorized into oceanic (maritime)climate, the Mediterranean, humid subtropical, continental, arid or semi-arid climate type.

Figure 69: Case studies, their location and climate conditions.

Figure 70: Traditional American medical campus scheme with thick building footprint and only limited accessibility to daylight.

Figure 71: Perforated, articulated buildings with narrow building footprint to maximize daylighting and connections to nature, Hospital Basel, Switzerland.

Urban Planning: Every building creates a shadow. Therefore the location, footprint and height of a building must meet local solar regulations when defined which regulates distances and heights to ensure the accessibility of daylight for surrounding areas and buildings. Even where regulation does not exist, it is critical to be a good neighbor for existing buildings both on and surrounding a project site, as well as the potential impact on future development.

Orientation and Shape: The orientation and shape of a building dictates the potential availability for daylighting. For instance, thick building footprints that are not perforated have only limited availability of daylight due to their minimal building perimeter (Figure 70). Articulated or perforated forms with narrow building footprints however increase the potential for daylighting due to their longer perimeter walls (Figure 71). Typically hospitals are build with a north/ south orientation. This orientation would be preferable because of thermal control, however it results in significant room qualities: The south side will receives much sunlight, northern rooms receives no direct sunlight, only a reduced amount of diffused daylight enters the buildings from the north. An eastern/ western orientation is preferable from occupants preferences, however it is more difficult to control sun penetration due to shallow sun angles on eastern and western facades (Hausladen, G. et al, 2006) (see also Guidelines Section: Guideline 1 Orientation and Shape).

Building envelope and openings: The building skin creates a filter between the interior and the exterior. Openings in it allow the exchange of light and air and provide visual connections to the outside. It also must control sunlight penetration to minimize unwanted heat gain, lighting and glare. Each orientation requires unique skin and apertures design for eastern, southern, northern and western exposures such as exterior shading systems including vertical or horizontal blinds, sliding shutters and low-emission glazing.

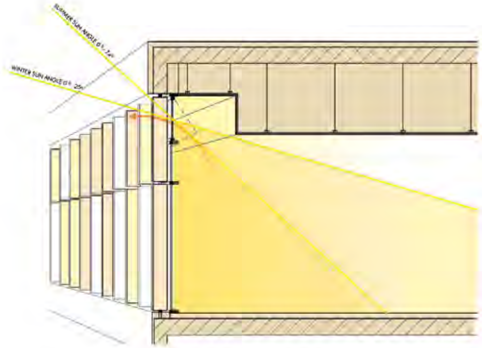


Figure 72: Vertical blinds for eastern/ western facade for non-inpatient area.

Control: Daylight can enter a building indirectly or directly through toplighting, sidelighting and guided light. It is important that the distribution of light is controlled by sun-protection glazing and exterior and/ or interior shading devices to avoid glare, distraction and heat gain which would compromised the indoor room quality. Due to the sun's changing positions and intensity throughout the day and season, shading devices need to address particular challenges for each facade orientation. Figure 72 illustrate a shading strategy with vertical blinds for the eastern and western facade. Depending on the functional use of space, these shading devices should be individually adjustable by building occupants (Figure 73).

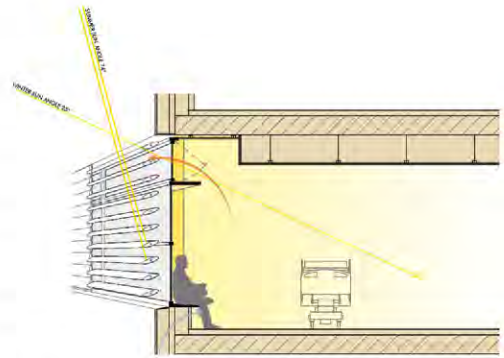


Figure 73: Horizontal blinds on southern facade for an inpatient area.

GUIDELINE 1: ORIENTATION AND LOCATION

Definition: The orientation of a building has an influence on the direction of solar radiation in summer and winter and wind loading. The best building orientation is based on climate zone, site location (urban or rural) and physical local conditions such as main wind direction to promote daylighting and natural ventilation. Thus, there can't be a universal orientation concept for healthcare buildings because, based on the functional use and requirements for a space, each orientation has its advantages and disadvantages (Figure 74). A building orientation along east-west axis is preferable for thermal control, however this orientation results in differences

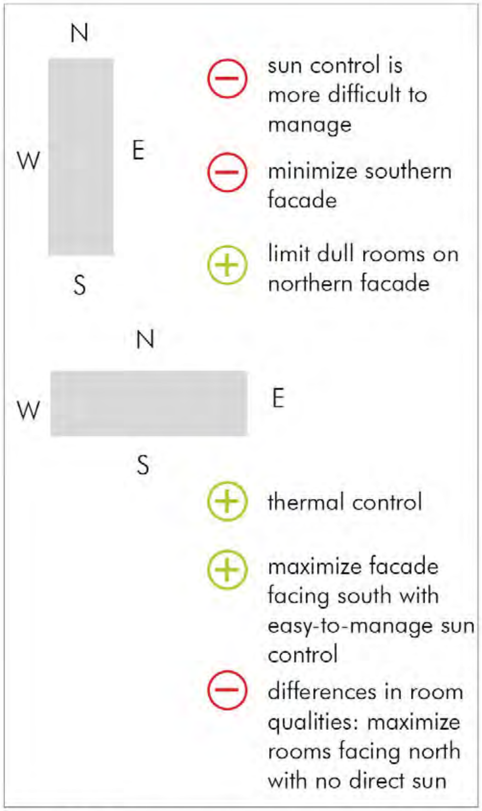


Figure 74: Building orientation and its advantages and disadvantages.

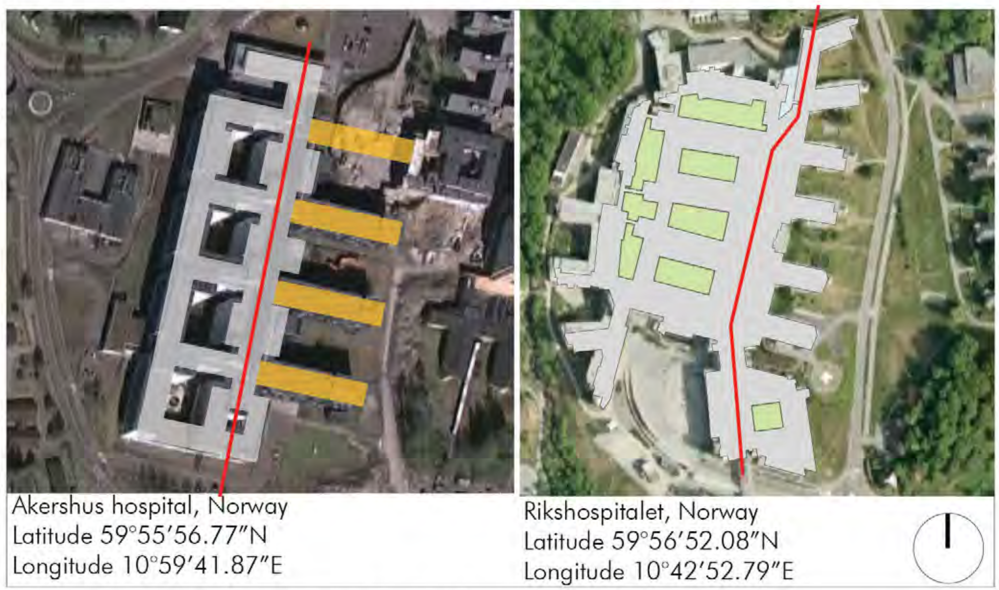


Figure 75: Hospital oriented along north/ east with inpatient units oriented east/ west.

in room qualities, due to their location either on the south facing perimeter or the northern perimeter without direct sunlight at all. The southern facade receives sunlight at a steep angle which makes it easier to control than eastern or western facades, that receives sunlight at shallow angles. The Akershus hospital in Norway is one built example for this orientation (Figure 75). The main circulation boulevards (red line) is oriented along the north/south axis, thus the inpatient units (yellow) are oriented along the east/west axis. Another hospital based on the same orientation is the Riks Hospital, also in Norway and illustrated in the same Figure. Both hospitals address natural wind conditions and enables widespread natural ventilation throughout the facility because of their orientation and their narrow building footprint. Most of the patient rooms are located on the southern side whereby all supporting rooms are locate on the northern side. However there are also patient rooms on the north which may have negative impact on the recovery process of patients as several studies about mortality rates, length of stay and perception of pain and stress suggest (see chapter 2: Daylight and Health).

With an east-west orientation in narrow double loaded corridor wings, every rooms would get direct sunlight during the morning or during the afternoon. However, especially on the western side, sun control needs to be designed carefully to achieve a comfortable room climate for occupants without heat gain, distraction or glare due to shallow sun angles. The inpatient units of Katta hospital in Japan are oriented that way (Figure 76). The overall building orientation is not predominant but all inpatient units are facing east and west, integrating a roof terrace between each wing.

Kattal Hospital, Shiroishi City, Miyagi, Japan:
Latitude 38° 0'37.04"N
Longitude 140°36'48.55"E

Figure 76: Hospital oriented along east/ west with inpatient units oriented north/ west.

The review of case studies reveals that there is a wide variety of building orientations in healthcare facilities designed for high levels of daylight. Notwithstanding this variety, the majority of the reviewed hospital orient their inpatient units along the east/ west axis such as the Dell Childrens Hospital in Texas and the KIZ Childrens Clinic in Austria (Figure 77).

Rehab, Basel, Switzerland
Latitude 47°34'19.81"N
Longitude 7°33'36.85"E

Dell Childrens Hospital, Texas
Latitude 30°18'8.93"N
Longitude 97°42'24.29"W

KIZ Innsbruck, Austria
Latitude 47°15'44.05"N
Longitude 11°23'14.92"E

Figure 77: Different hospital footprints and their orientation.

GUIDELINE 2: NARROW BUILDING FOOTPRINT

Definition: Narrow building footprints can help to provide both improved daylight and the opportunity for natural ventilation in public, patient care and work spaces. Hospitals in most European countries are required to have narrower building configurations and operable windows that enable them to have widespread access to daylight and utilize natural ventilation when exterior weather conditions permit and interior needs can be met without mechanical conditioning. Hospitals in Europe typically are laid out with narrow wings and/or contain courtyards and atria to provide occupants with almost universal access to daylight, views to nature and natural ventilation.

Figure 78: Street-hospital typology, Rikshospitalet, Oslo, Norway.

A common hospital typology for new hospital building in Europe is the street-typology (Figure 78). This hospital configuration is generally horizontally organized. Narrow patient wings and care areas with plan-enclosed courtyards are organized along a connector, the "main street" (Figure 79). This circulation spine is often built as an atria with similar character to a real urban street.

Figure 79: Street-hospital typology, "main-street" of Akershus Hospital, Norway.

While natural ventilation is not the main topic in this thesis, a short description may be necessary to illustrate further the potential of connecting hospital spaces to the outside by natural ventilation. Natural ventilation describes the principal when outdoor air is moved through building or space because of natural forces (e.g. winds and thermal buoyancy force due to indoor and outdoor air density differences). A

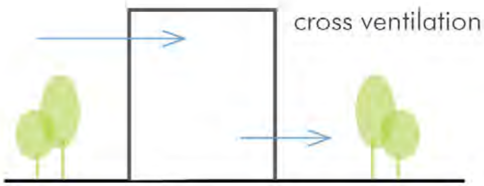


Figure 80: Principle of cross ventilation.

narrow building footprint can support the effect by its location and configuration if the main wind directions and site conditions are considered. In addition the design of the building's envelope including windows, doors, solar chimneys, wind towers and trickle ventilators should be carefully considered. For instance, in the United Kingdom, the National Health Service policy tends to limit the adoption of mechanical ventilation to the principal medical treatment areas or what would be considered diagnostic and

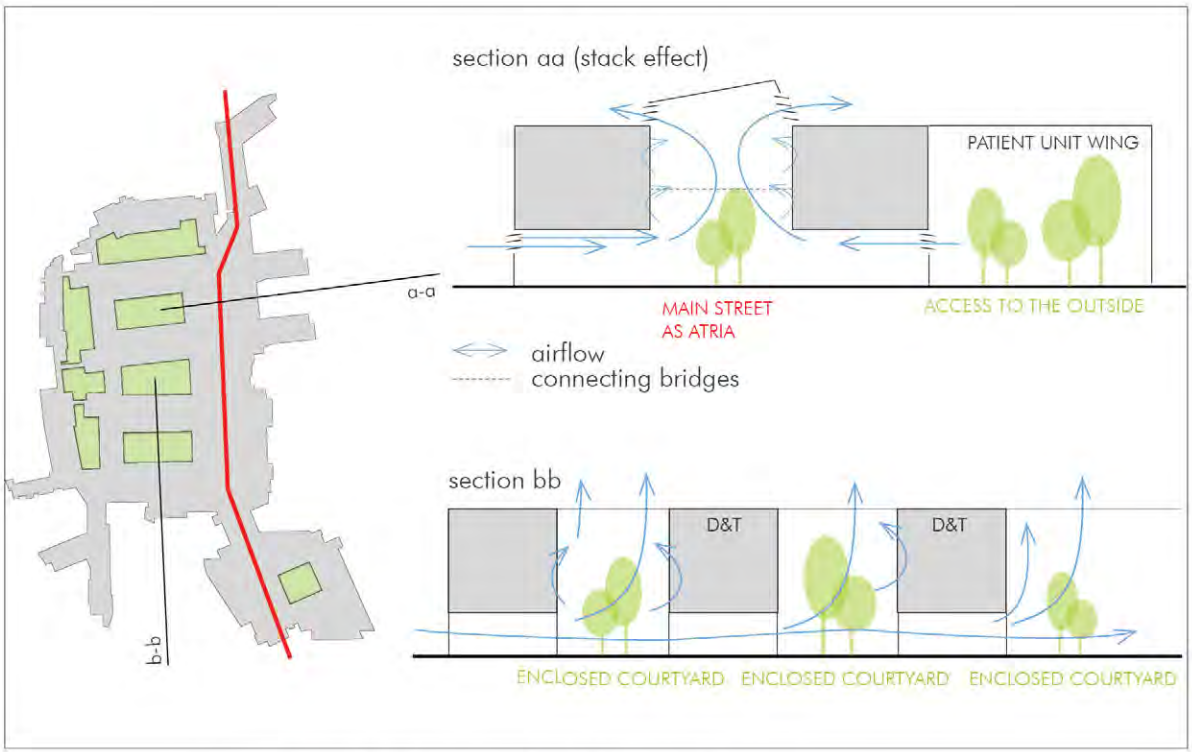


Figure 81: Natural ventilation principles, Rikshospitalet Oslo, Norway

treatment areas in the US. Patient wards are usually not required to be mechanically ventilated, and ventilation through opening windows is usually the most common solution. (Atkinson, J. et al. 2009)

Concepts: The Rikshospitalet University Hospital in Oslo, Norway is a great example for narrow footprint in combination with a connecting main street as atria. This building configuration allows for natural ventilation in most areas of the building, using different ventilation concepts such as the stack effect (Figure 81: section aa) and cross ventilation. Narrow patient unit wings are attached to a long connector, the “main street”. This connector is built as an atria with side opening at the top. The atria is natural ventilated using the stack effect, illustrated in section aa. Fresh air enters into the building through controllable openings in the facade at the ground level and is exhausted through smaller side openings at the top of the atria. In case of the 60’ wide courtyards in the D&T block (Figure 81: section bb) fresh air flows from the windward side to the side sheltered from the wind through the ground level and enclosed courtyards into the building and out.

Another example of an articulated, perforated or narrow hospital, however in a much smaller scale, is the Alltwen Community Hospital in North Wales, England. This Community hospital is located in a rural setting and provides almost universal contact with nature. To optimize the use of natural light, natural ventilation and heating strategies, the hospital is split level and organized around an atria which is used as a main street, connecting all departments (Figure 83). The atria is covered with a glass roof to maximise daylighting and side openings along the glass roof creates a stack effect to assist natural ventilation as illustrate in Figure 84. Clerestories along the circulation of inpatient areas are used for illumination of the space and outlets for air. Areas where access to the outside is limited by clinical needs are mechanically ventilated or ventilated in a mixed mode (Figure 85).

Figure 82: Narrow building footprint of Alltwen Community Hospital.

Figure 83: Main atria with glass roof and clerestories along corridor of inpatient unit.

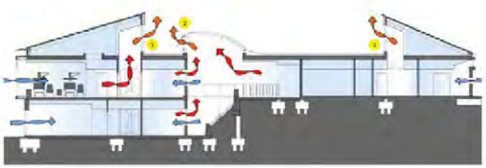


Figure 84: Section illustrating ventilation concept.

Figure 85: Department overview and ventilation concept.

GUIDELINE 3: PERFORATED THICK BUILDING FOOTPRINT

Definition: When narrow building footprints are not feasible, thicker floor plate areas should be perforated with courtyards and light wells whenever, and as frequently as, possible. While almost all areas of contemporary hospitals in many parts of the world are still built with narrow wings of functional space, most hospitals in the US organize their diagnostic and treatment in thick building footprints with a very low percentage of area exposed to daylight. Most treatment and staff working areas are artificially lit, fully air conditioned and without connections to the outside. The technologies, events and experiences that occur in these spaces are inherently intimidating and highly stressful. Given that an increasing body of literature is citing the potential of daylight and connections to nature for stress reduction and other benefits to patients and staff (Kueller, R., 2006; Mroczek, J. et al., 2005; Alimoglu, M.K., et al., 2005; Scott, H., 2000; and Leather, P., et al., 1998), it seems that these areas are most in need of increased access to these conditions. Thicker building footprints in diagnostic and treatment areas are also driven by the critical need to optimize departmental and interdepartmental functional relationships, and minimize travel distances for staff. These drivers may be less relevant today when functional efficiency is measured less by direct visualization and time and motion, and increasingly about information technology and virtual connections. However, these departments, more than other areas of the hospital, will still need to consider critical proximity relationships. While there is some debate on the issue of hermetically sealed settings and health, there is little doubt that the needs of technologies in these spaces will still demand mechanical

Figure 86: Perforated building footprint of Dell Children's Medical Center in Austin, Texas.

Figure 87: Perforated D&T department, Palomar Pomerado Health, California.

Figure 88: Project information, Palomar Medical Center.

ventilation and artificial light in many instances. That however does not preclude the potential for introducing both daylight and view to nature through the introduction of courtyards and light wells.

An increasing number of contemporary examples of diagnostic and treatment departments in the US, including surgery and interventional medicine, indicate that it is possible to penetrate these areas of the hospital with courtyards and retain efficient and flexible functional layouts. Palomar Pomerado Hospital by CO Architects with medical planning by CO Architects and Anshen+Allen is one example (Figure 88). As one of the first hospitals in the US, the diagnostic and treatment center integrates two plan-enclosed courtyard along main circulation corridors. Along with skylights, these courtyards provide the majority of staff working areas with daylight and achieves a daylight area of 28 percent.

Concepts: A perforated building with integrating plan enclosed courtyard[s] has the advantage of no dead-end corridors and is used for diagnostic and treatment as well as for emergency departments. As shown in Figure 88, courtyards are placed along main circulation corridors at staff work points or department's boundaries as seen in the new diagnostic and treatment building of Palomar Pomerado Medical Center which will be finished in 2011.

Another example of courtyards integrated in diagnostic and treatment departments is the design proposal from Stantec for the urgent care of the emergency department of

Nanaimo, Canada. This project organizes two 20' by 24' courtyards between two nurse stations and surrounded by treatment pods allowing daylight and outside views from staff working and patient care areas. The courtyards replace former support and supply areas being relocated between two pods with almost no difference for travel distances within and between the care pods. Thus 66 percent of all care areas are daylit and within 15' of building's perimeter. To ensure energy savings these areas are equipped with light responsive control systems. The department net to gross factor is 1.61, not more than average and according to the architects Stantec the benefits are much higher than the initial costs for the increased wall perimeter. Even applying a very conservative potential benefit of a 3 percent improvement in staff-related costs, the courtyards would pay for themselves in three to nine years.

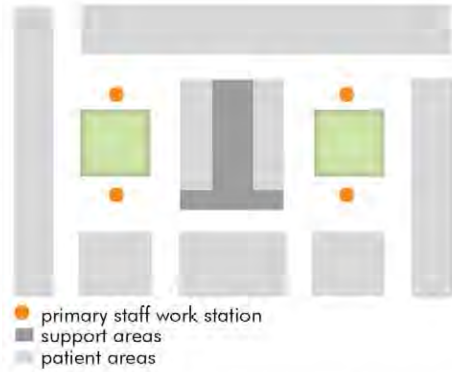


Figure 89: Courtyards in emergency department, Nanaimo, Canada.

The Dell Children's Medical Center, Texas, is the first hospital in the US being awarded with LEED Platinum certification. The hospital integrates seven plan-enclosed courtyards in its footprint and thus increases the perimeter wall and its potential for daylighting and views of the hospital substantially: 60 percent of occupied spaces unrestricted by clinical needs and 35 percent of spaces in diagnostic and treatment have access to daylight, most areas are no further than 32 feet from a window. The courtyards are partly accessible from the public or patient areas and used as healing gardens and places of respite.

Figure 90: Groundlevel with courtyards, Dell Children's Hospital.

GUIDELINE 4: COURTYARDS IN INPATIENT STAFF AND PUBLIC AREAS

Figure 91: Courtyard within psychiatric inpatient unit, Östra Hospital, Sweden.

Definition: Courtyards offer the opportunity to illuminate central spaces with daylight. In rectangular or race tracked planned inpatient units enclosed courtyards can be located in the core, surrounded by patient rooms, support areas and nurse station as in the Inpatient unit of the Psychiatric Hospital in Oestra, Sweden (Figure 91). Important key factors of successful courtyards regarding daylighting are the size of the space in relation to the height of the building and its shape, the location, the accessibility and orientation, floor surfaces, materials and plants. Traditional courtyards and light wells are most effective in low to mid-rise buildings. However, high rise buildings also can integrate courtyards within their facility when properly designed to maximize access to daylight. They can also be used to promote natural ventilation.

Concepts: Courtyards in inpatient unit influence the building configuration, shape and inpatient unit concept. Design studies from built examples around the world indicate the successful use of courtyards in patient unit layouts. There are a variety of concepts to integrate a single or several courtyards within a unit. For instance, courtyards can be integrated within the support area of a racetrack scheme as seen in Figure 92 "race track scheme" illustrated by the University Hospital in Innsbruck on the following page. The Rehabilitation Center for Spinal Cord and Brain Injuries in Basel, Switzerland illustrates a a perforated block scheme, combining several inpatient units on one floor. Four inpatient units are combined on one floor, organized around 10 courtyards. With these courtyards 67 percent of the total floor area is daylit and within 15′ of the building perimeter (Figure 92).

The Katta Public General Hospital in Japan includes as a large assembly of inpatient units on the top floor of the facility (Figure 92). The inpatient floor itself is broken up into narrow wings organized along central spines. Each inpatient wing has its own roof terrace with individual access from each patient room.

Courtyards are located along circulation space close to the primary work stations and are directly attached to the examination and office space of the Intensive Care Unit of the Community Hospital in Hameln, Germany (Figure 93). Courtyards can be located in the core of square inpatient units. In this case, they are surrounded by

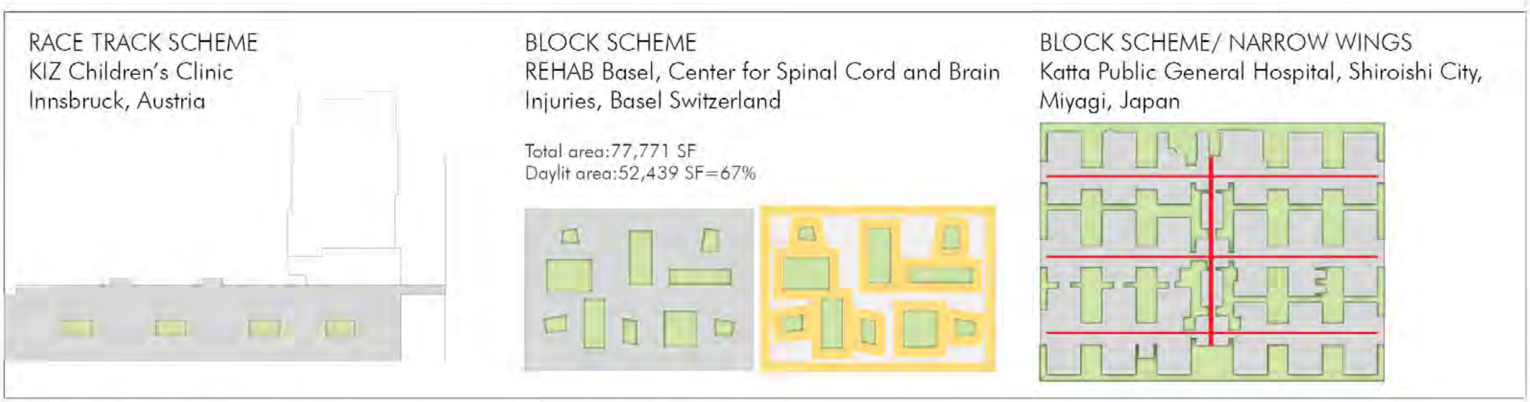


Figure 92: Schematic representation of inpatient units integrating courtyards.

support rooms and patient rooms as seen in Figure 94. This inpatient unit configuration provides daylight and outside views from primary work stations as well as short walking distances. Also, the courtyard can be integrated in a core support zone of a race track plan as built in the KIZ Children's Hospital in Innsbruck , Austria (Figure 95 and spreadsheet Figure 99) The configuration of the unit is organized as a double loaded floor with a total width of 95'. The courtyard's floor dimensions are 25' x 46' and its sides are all fully glazed. The primary work station as well as the examination room are directly next to the courtyards. In addition to the courtyard the unit include a balcony next to the staff break room to provide physical access to the outside.

For optimal sun penetration, courtyards should be oriented with the long dimension

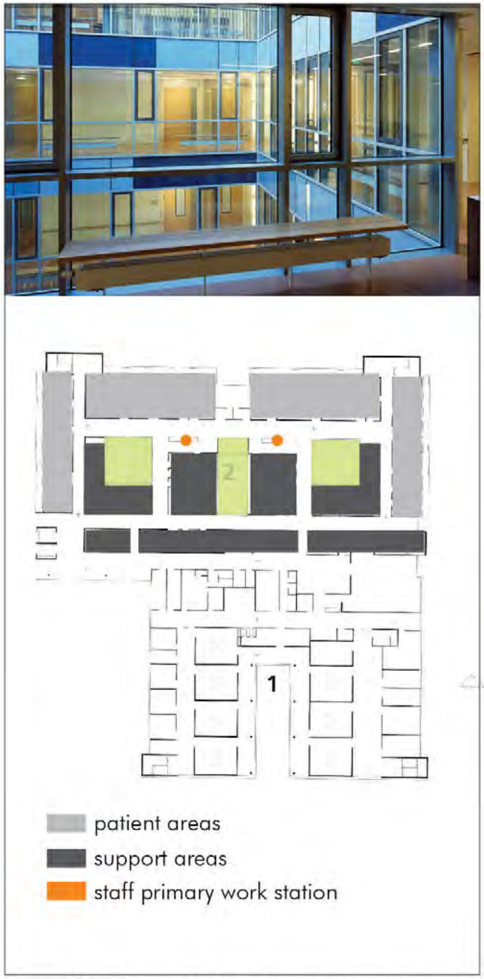


Figure 93: Courtyard within intensive care unit, Hospital Hameln, Germany.

Figure 94: Radial plan in inpatient unit with courtyard in its core, Hospital Agatharied, Miesbach, Germany.

Figure 95: Race-track plan with courtyard in core areas of inpatient unit, KIZ Hospital, Innsbruck, Austria.

generally south-north as illustrated in Figure 96. Decreasing the height of the surrounding building on the southern side increases the availability of direct sunlight into the courtyard and courtyard surface. Courtyards that are always in shadow should be avoided unless in consistently hot climates or built as an enclosed atria so that they are tempered. Another way to increase direct sun penetration is to increase the upper perimeter area of a courtyard. The courtyard can be cone or wedge-shaped, built with sloped walls or the top floors can be stepped back.

According a study of Muhaisen, A.S. & Gadi, M.B in 2005, analyzing different courtyard sizes and shapes, the ratio of the courtyard's floor perimeter to the height should be equal or greater than five (Figure 96). The study also found that deep courtyard forms achieve maximum internal shaded areas in summer while shallow forms have the advantage of optimizing sunlit areas during winter.

The GGHC (Green Guide of Healthcare) requires a minimum width of the courtyard per floor of 15 feet or at least a total width of 60 feet to qualify as outside area for the calculation of daylight areas. Atria with a glass roof need a minimum width of 10 feet per floor or need to be at least 40 feet wide to qualify as outside area. Bright surfaces on the ground of smaller courtyards increase the illumination level through reflection of diffused light. In courtyards of the inpatient unit in Japan (Figure 97) as well as in the courtyard in a children's hospital in Germany this was achieved by using white pebble (Figure 98). In this case the courtyard is also used as space for art exhibitions.

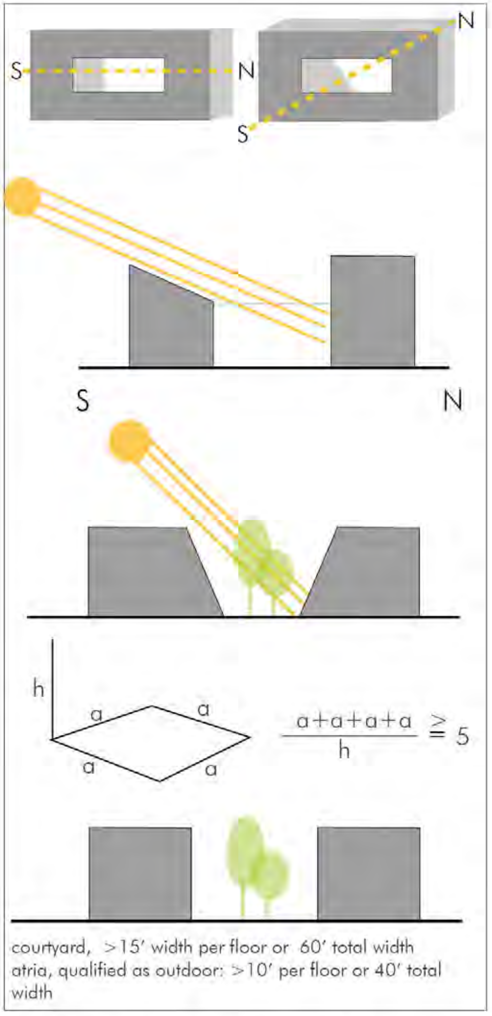


Figure 96: Courtyard design principles for optimized daylighting.

Figure 97: Inpatient rooms with direct access to enclosed courtyard Katta Hospital, Japan.

Figure 98: Sloped courtyard with displayed art, Children's Hospital Biel, Austria.

Three detailed case studies are attached at this guidelines to illustrate potential design applications: KIZ Childrens Hospital in Austria, REHAB in Switzerland and Katta Hospital in Japan. The spreadsheets include photos and diagrams and illustrate the location and dimension of courtyards, their relationship to primary work stations, the building heights and general organization of the unit.

Figure 99: Spreadsheet KIZ Children's Hospital, Austria

Figure 100: Spreadsheet, REHAB Basel, Switzerland.

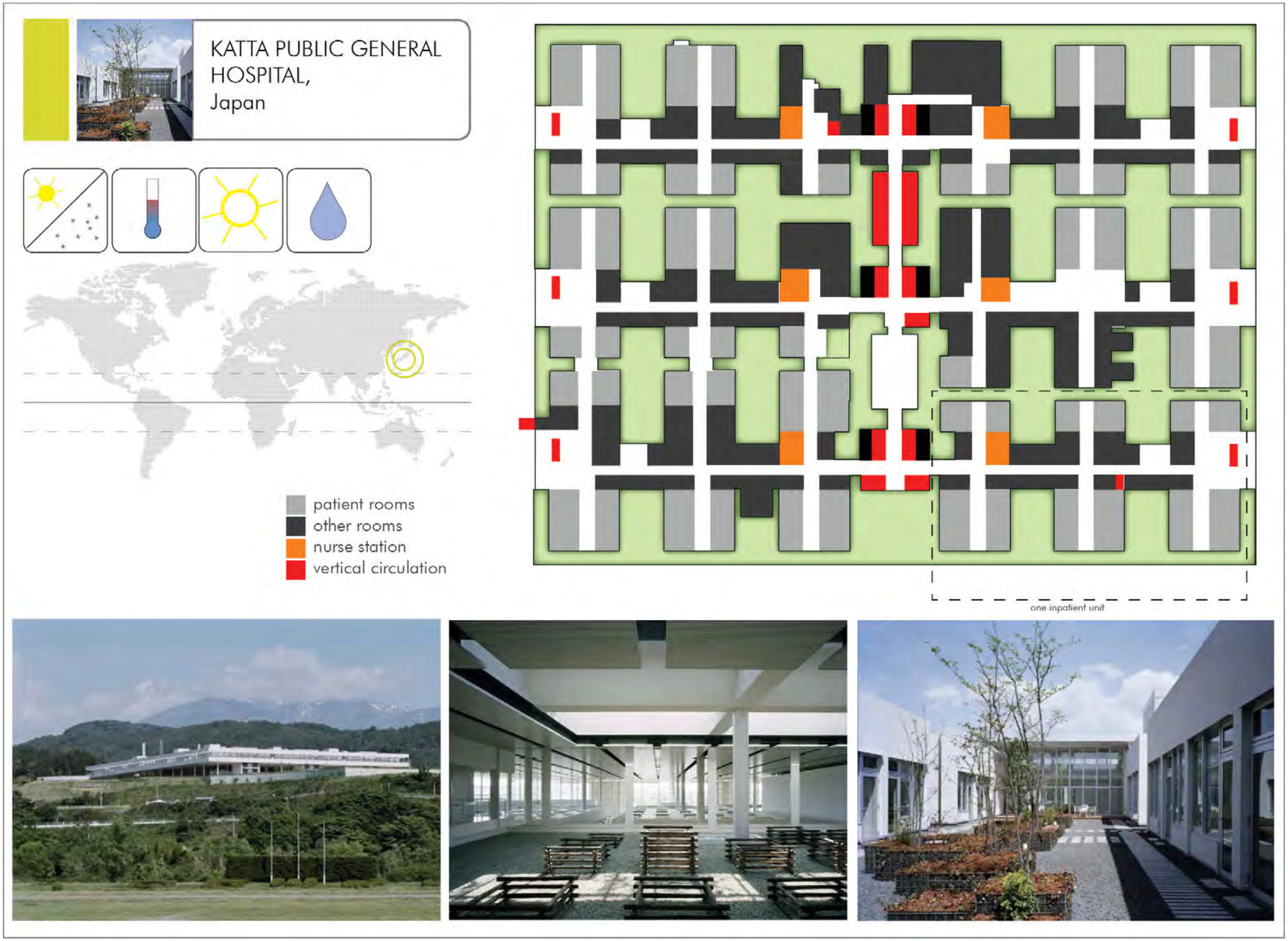


Figure 101: Spreadsheet, Katta Public General Hospital, Japan

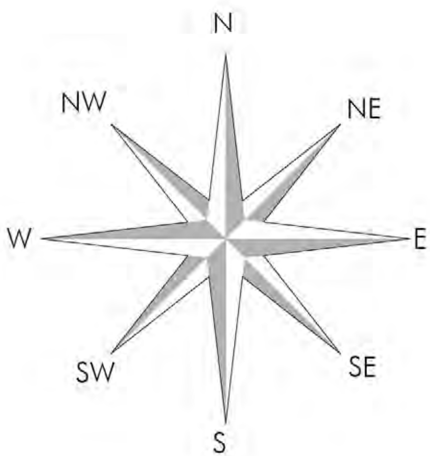


Figure 102: Directions.

Figure 103: Tempered climate zone on the northern hemisphere.

GUIDELINE 5: SHADING

Definition: A successful daylight concept needs to integrate sun control strategies to avoid heat gain, distraction and glare, especially on southern and western facing facades. Otherwise visual and thermal comfort of building occupants as well as building's heating and cooling demands would be affected negatively.

Due to the sun's changing positions and intensity throughout the day and throughout the season, successful daylight architecture requires shading devices controlling and redirecting direct sunlight. These strategies address particular challenges for each facade orientation. Studies in office building have shown that occupants take action to eliminate or reduce daylight entering the space, if heat gain, glare or distraction are not address appropriately (Boyce et al. 2003). Sun control is also important to reduce energy use. The cooling energy demand rises almost proportional to the dimension of the glazing on eastern, western or southern facades if there is no sun control.

Sun control functions in different layers. The first, the exterior one, must be designed to block or redirect sunlight to avoid heat gain and glare. Often, these systems are integrated in the exterior second skin of a double skin facade. The next layer is the glazing which should typically be a double pane low emission glazing, filtering most of the ultraviolet light and some of the heat. The next layer is interior sun control. This can be for instance, curtains, blinds or sunscreens. Interior sun control is not effective against heat gain, because the heat is already in the rooms, however it is effective to control glare and provide individual lighting control by building occupants.

Concepts: Shading concepts in this thesis address the particular conditions and challenges in temperate climate zones, because most of the area of the US and Europe is located within this moderate climate, characterized by seasonal change, low to medium temperature variations and low to medium exposure to solar radiation.

Southern facades are exposed to direct sunlight during midday and benefit from shading devices as horizontal louvres to block direct sunlight during summer seasons to avoid heat gain. However, during winter seasons the shading systems works differently. Instead of blocking, the shading supports deep sun-penetration into the interior space to take advantages of sun harvesting to heat the space. This can be achieved by one shading system because of steep sun angle during the summer and shallow sun angle during the winter.

On northern facades there is no or only minimal direct sunlight during sunrise and sunset during summer months when the sun rises above the east/west axis Therefore the glazing usually needs no shading devices and clerestories can be realized that offer indirect skylight without solar heat gain. Due to potential heat loss during the winter season through glazing, low emission glazing should be used and in cold locations triple panes are appropriate. Thermal comfort of occupants might be influenced by low surface temperature of glazing. Interior privacy protection also needs to considered.

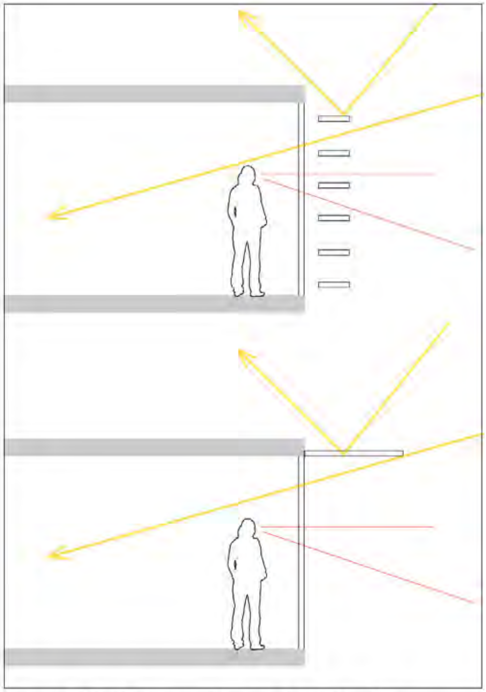


Figure 104: Sun control on southern facades.

Figure 105: Horizontal shading devices for patient units.

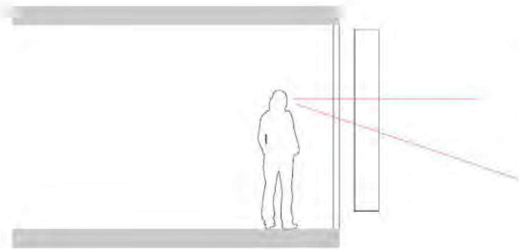


Figure 106: Vertical shading devices for western and eastern facades.

Figure 107: Vertical shading devices for inpatient units, Dialysis Clinic, Vienna, Austria

Eastern facades are exposed to direct sunlight from sunrise till midday and therefore call for shading devices dealing with shallow sun angle. During most of the year, heat gain is not as much an issue as on western facades because the sun hits the facade during the morning when the outside temperature is still cool from the night. However, because of heat gain issues during summer season, vertical shading devices are needed to block the sun and to avoid glare for occupants.

Shading the western facade orientations of buildings are, besides the southern exposures, the most important with respect to minimizing heat gain and glare, but they are often neglected. The sun hits the west facade during the afternoon when it has still a lot of intensity and due to shallow sun angles, the sun penetration into the building is often difficult to control. Without shading, the sun could produce excessive heat gain and glare in the interior, resulting in occupants discomfort. Appropriate shading strategies are, similar to the eastern facades, to install vertical solar screening which are efficient as well as let enough daylight into the room and provide a view out.

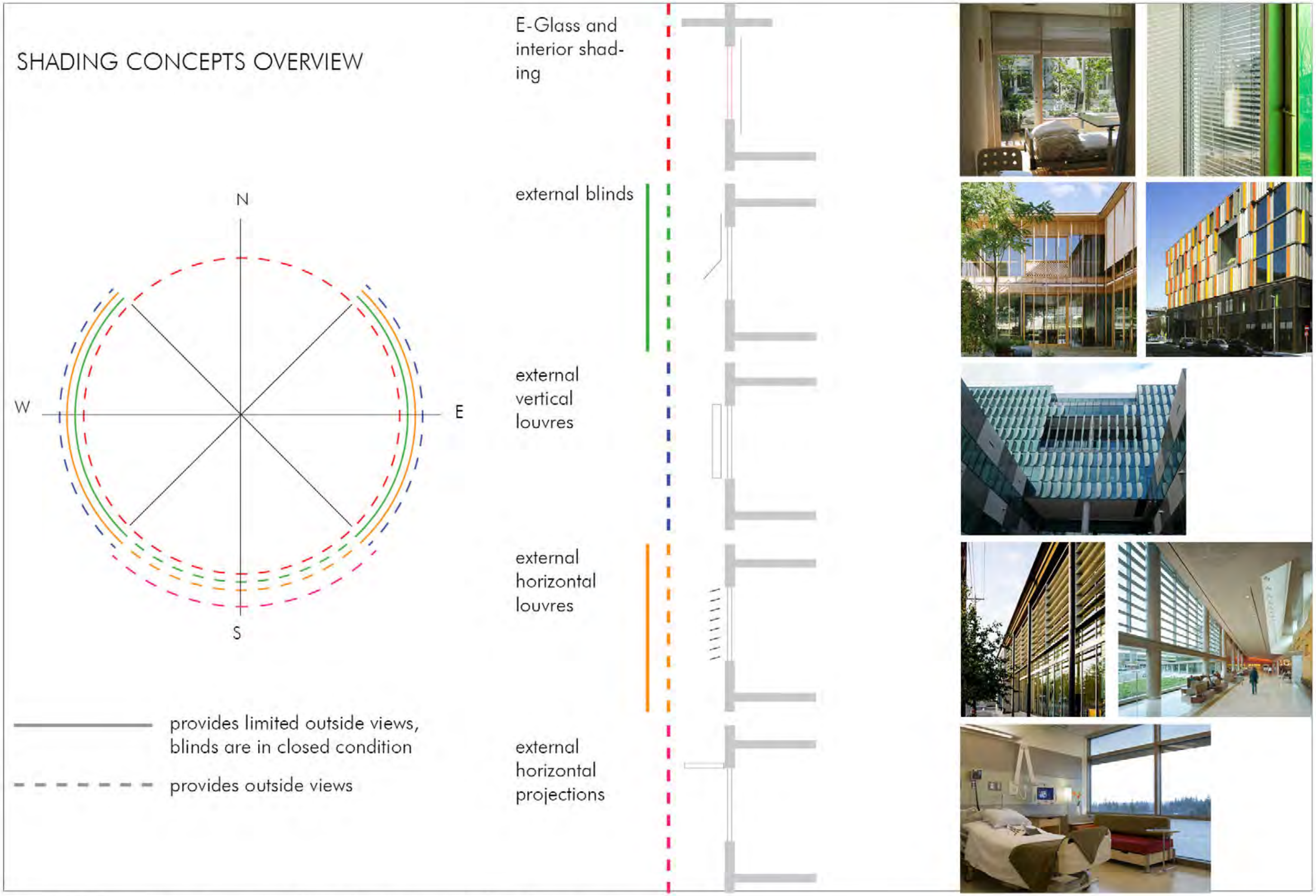


Figure 108: Spreadsheet illustrating different shading concepts for different directions.

GUIDELINE 6: SKYLIGHTS AND CLERESTORIES

Figure 109: MRI room with skylight- a space that normally does not have access to daylight.

Figure 110: Skylights at the bottom of courtyards provide daylight for the story below.

Definition: Skylights and clerestory windows offer opportunities to introduce daylight into the interior core areas of large building footprints when courtyards or light wells are not possible. They are appropriate for interior corridors, corridor intersections, waiting areas, exam and procedure rooms (Figure 109), offices, nurse stations and other staff work areas on the top floor of buildings when these spaces do not have access to windows on an exterior wall. They can also be used to provide a secondary daylight or ventilating source in rooms with windows. When employed in spaces located below of courtyards and light wells, they can allow light to penetrate deeper into multistory buildings (Figure 110). Skylights in these applications provide staff, patients and visitors in areas not normally exposed to daylight or connections to nature with a sense of the time of day and weather even if they have no direct views outside. These features can be especially beneficial to staff who work long shifts in spaces normally devoid of daylight. Studies indicates that the absence of daylight could result in lower concentration and productivity (Heschong, L. et al. 2003, Heerwagen. J.H., 1998, Boyce, P. Rea, M.S., 2001), increase perceived stress and lower satisfaction and could also result in higher staff turnover rates (Kueller, R., 2006, Mroczek, J. et al., 2005, Alimoglu, M.K., et al., 2005, Scott, H., 2000, and Leather, P., et al., 1998). When properly located and designed, skylights and clerestory windows help to reduce energy consumption due to decreased use of artificial lighting which lowers internal cooling loads caused by artificial light source (Burpee, H.& Loveland, J. 2010, Hausladen, G., et al., 2006, Roisin, B. et al., 2008) It is critical that they are oriented and designed to avoid glare, hot spots on surfaces and excessive heat gain, especially in warm climates and hot seasons. A variety of design features can be employed to screen, filter, reflect and redirect sunlight in ways that provide a high quality light source. Employ vertical clerestory glazing screened from direct sunlight penetration or place clerestories facing north (Figure 112). Exterior sun control strategies include vertical or horizontal blinds (Figure 111), low-emission glazing, glass frittings, diffusing features and redirecting blinds (Figure 112). To maximize visual performance, task work surfaces and digital display units must be completely screened from direct sunlight. Control and sensing technologies can be employed to automatically adjust operable screening and filtering features in response to both interior and exterior conditions in order to optimize lighting and thermal performance. Skylights and clerestory windows can also function to support and induce natural ventilation in appropriate climates allowing warm air to rise and exit interior spaces.

Figure 111: Horizontal blinds and redirecting panels for exterior sun control.

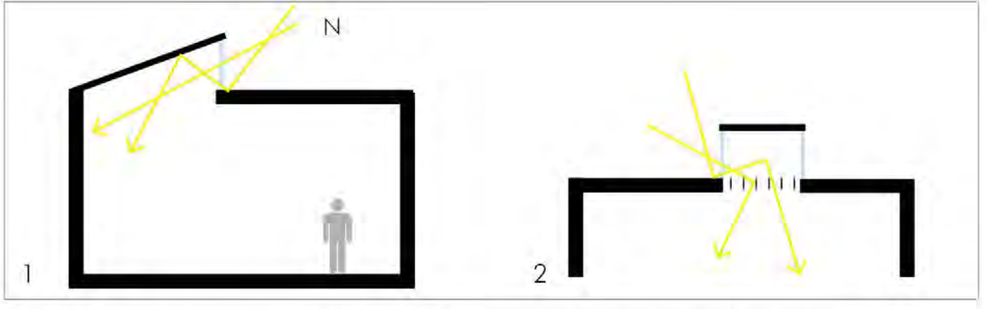


Figure 112: Sun control strategies diffuse daylight distribution: clerestory facing north (1) and clerestory with redirecting blinds (2).

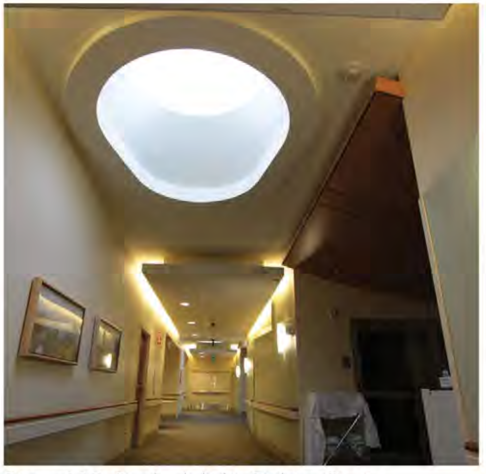


Figure 113: Single skylight, Birthing Center, Gastonia, SC, US

Figure 114: Clerestories above nurse station of ED, St. Mary's Hospital, Walla Walla, US

Concepts: Provide skylights or clerestory windows designed to optimize appropriate exposure to daylight in work areas that do not have windows, where critical patient care tasks occur, and where staff work for more than fours hours at a time. Also provide skylights whenever possible in major patient movement corridors and in critical circulation areas. Skylights or clerestories can be placed as a single skylight (Figure 113) or daylight strips in circulation areas as seen in the corridor of the emergency department of St. Mary's Hospital in Walla Walla (Figure 114) or in the inpatient unit of the Knittelfeld Hospital in Austria (Figure 115). This inpatient unit is an excellent example for daylighting trough skylight/clerestory elements. In compensating for the deficits of the chosen location, (the extension is located on the northern side of the existing hospital) the walls of the inpatient units are sloped to design a volume flooded with light down to the lowest level. Daylight is transmitted through skylight strips deep into core areas of the inpatient unit. Mirrors on the sloped

Figure 115: Deep sun penetration through skylight, mirrors and sloped walls, Knittelfeld Hospital, Austria

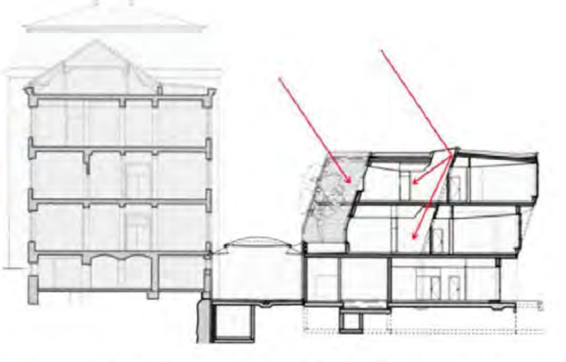


Figure 116: Section through inpatient unit, Knittelfeld Hospital, Austria

wall and the bright surface reflect the light and increase the illumination level. The design of the skylight elements and light wells allows daylight to penetrate even into the lower levels of the addition (Figure 116).

The higher a window is on a wall, the more effective it is for daylighting. This approach for high illumination levels is illustrated in Figure 118 and in the ICU of Alfred Hospital in Australia (Figure 117) where clerestory windows provide maximum daylit areas. In addition the light is diffused by switchable glazing and redirected by the wooden surface of an inverted ceiling element. If skylights are the main source for lighting, such as the clerestories in the ICU, skylight spacing can be calculated with following calculation: skylight spacing (S) = 1 to 1.5 x ceiling height (h). Their daylight area is [according to GGHC] the floor areas directly under skylights equal

Figure 117: High clerestories in Intensive Care Unit for effective daylight penetration, Alfred Hospital, Melbourne, Australia.

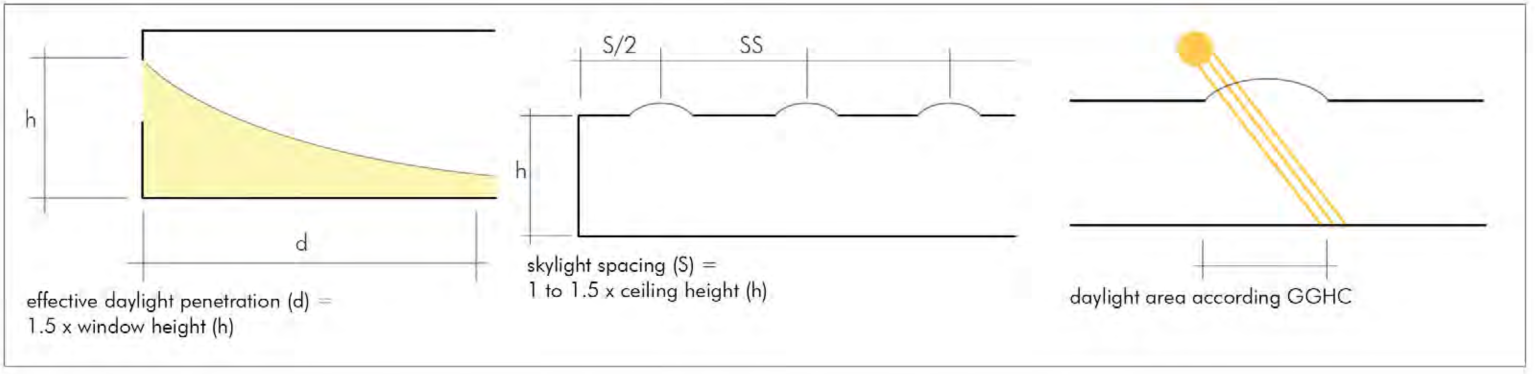


Figure 118: Effective daylight penetration, calculation of skylight spacing and qualification as daylight area according to GGHC.

6 DESIGN

The design of a daylight hospital must address local climate conditions. Therefore, in order to develop the proposed daylight hospital the climate zone needed to be determined at the beginning of the design process. A replacement community hospital for Norristown, PA, that is designed by Perkins & Will was chosen to implement and test the proposed dayligting guidelines. The new medical center for Montgomery County is part of the Albert Einstein Healthcare network and currently under construction, the completion is planned for fall 2011. The program of 146 beds represents a relatively common program for a replacement community hospital in the US. The Norristown project falls within the climate zone 4 which also includes most of central Europe and covers a wide zone of applicability in the US.

In contrast to the health systems decision to relocate the new medical center to a greenfield site in the suburbs of Norristown, this thesis design proposes to work within the existing context on a tight urban site to illustrate the potential and limitations of daylit hospitals in urban communities.

6.1 CLIMATE ZONE SELECTION CRITERIA

The continental U.S. includes a variety of different climate zones. A climate classification which is widely used for design guidelines, energy codes or standards is the 'DOE Climate Zones', developed by the U.S department of energy. This classification divides the U.S. into eight climate zones, ranging between hot (zone 1) to cold (zone 8). Some of them are further divided into three sub-zones, indicating moisture conditions as humid, dry, or marine sub-zones. The zones are defined by heating degree days and cooling degree days and can refer to political boundaries, such as state or county lines.

Figure 119: Climate zone 4
Climate zones (by county) for the 2004 Supplement to the IECC, the 2006 IECC, and ASHRAE 90.1-2004.

Comparing these heating and cooling degree days with Europe would result that northern Europe would be classified as climate zone 5-marine, and central Europe as climate zone 4- mixed marine. Hospitals in these zones in Europe are typically designed to optimize access to daylight and their design strategies could have applications for hospitals projects in the matching climate zone 4 in the US. Climate zone 4 is characterized by seasonal change, medium temperature and medium solar radiation, and was chosen for the design proposal because it represents a reasonable average climatic context in the US with a large potential area of application - not too hot and not too cold. Additionally, zone 4 exists at the west coast subcategory: marine) as well as at the east coast (subcategory: humid with hot summers).

6.2 PROJECT SELECTION CRITERIA

Figure 120: Unbundled hospital typology with patient tower and typically thick D&T block.

To represent a high number of possible applications for a daylit hospital the community hospital type, the most common hospital type, was determined for the design proposal. These mid-sized hospitals often segregate the diagnostic and treatment department (D&T) from inpatient areas and are typically built as thick diagnostic and treatment building footprint, connected to a tower and surrounded by parking. This building typology has widespread application and would potentially benefit from a design approach which increases the building perimeter to optimize daylighting and views to nature as main design driver.

Figure 121: City of Norristown 6 miles (10 km) northwest of the city limits of Philadelphia.

Location information: The existing Montgomery hospital is located in Norristown, a small town with 30,000 people living within the city limits. The city, incorporated in 1812, is located just 6 miles from the border of Philadelphia and its downtown is connected with the regional rail and bus transit system serving the broader Philadelphia area.

The site of the existing hospital is located within the urban core on the upper end of downtown Norristown on Fornance St, a main street connection from the east to the west part of Norristown. Public transportation on Dekalb St, one block to the east of the hospital connects the site with the downtown area. The hospital is surrounded by a small scale residential neighborhood and all blocks provide sidewalks which makes it, along with the denser development, a walkable district. Parking opportunities exist either along the street or in a parking garage on the hospital campus.

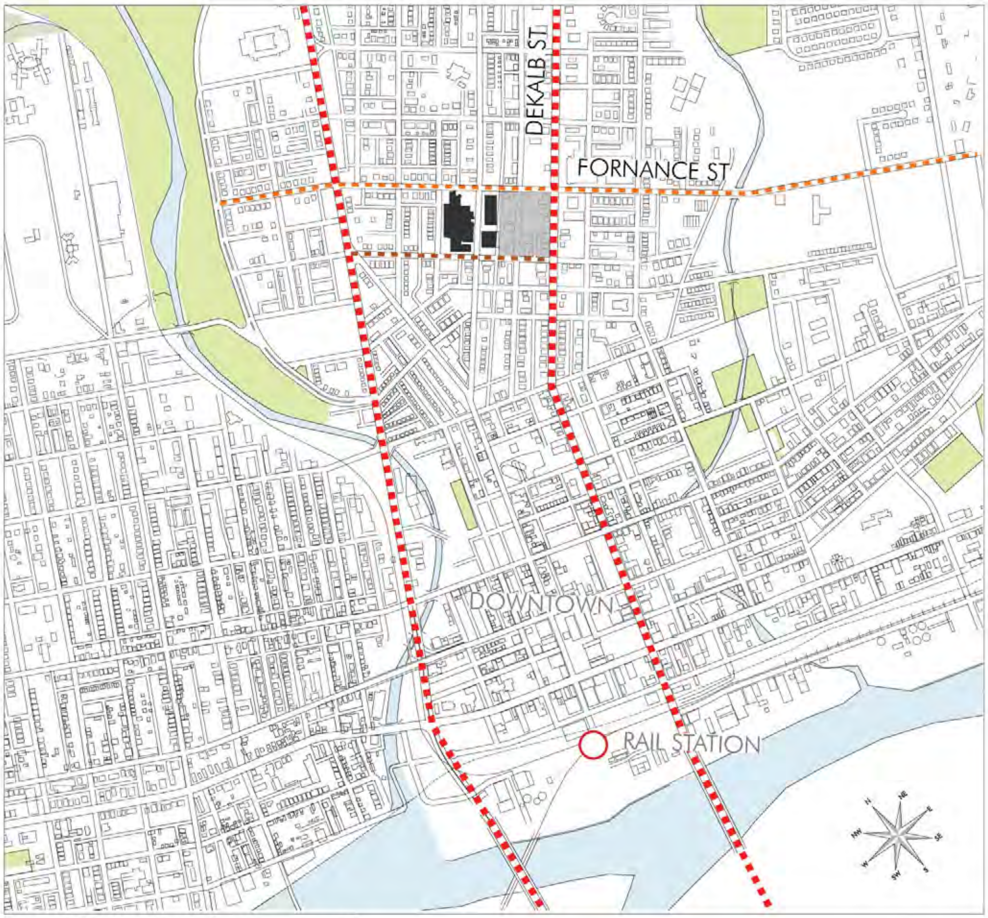


Figure 123: Location of existing hospital

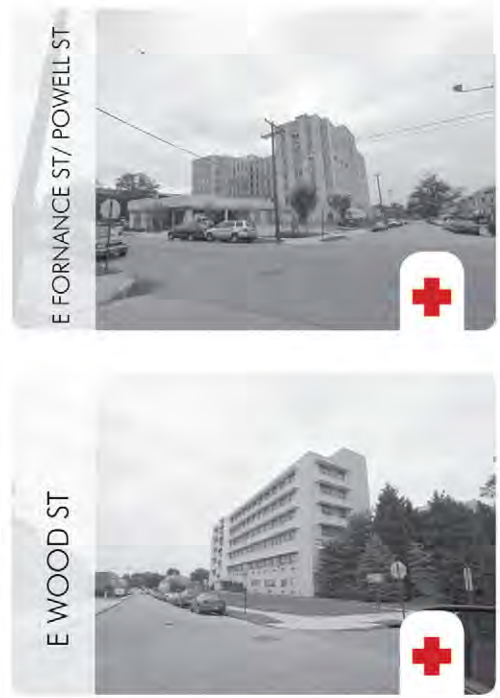


Figure 122: Existing Hospital of Montgomery County.

Project Program: The daylight hospital proposal uses the same program developed for the planned replacement for Montgomery Hospital and was developed by the architecture firm Perkins & Will. In addition to this program, the program for the thesis proposal will include an outpatient clinic within its building program. The actual replacement project excluded the MOB and the food service. They were outsourced and planned separately.

The program, attached on the following pages, includes clinical, administration, public and service space for the 146 bed community hospital. The proposed total area of the hospital in phase one is 337,120 BGSF (31,119 BGsm) and future growth is planned to expand the program up to 300 inpatient beds and double the space for the diagnostic and treatment platform.

Figure 124: Replacement hospital on greenfield site, rendering and site plan and floorplan level one.

PROPOSED BUILDING PROGRAM | COMMUNITY HOSPITAL FOR 146 BEDS

PATIENT UNITS	142,056 BGSF	13,197 BGsm
DIAGNOSTIC AND TREATMENT:		
EMERGENCY	25,274 BGSF	2348 BGsm
DIAGNOSTIC IMAGING	24,634 BGSF	2289 BGsm
SURGERY/ INTERVENTIONAL	47,554 BGS	4418 BGsm
LIGHT DIAGNOSTIC &TREATMENT	21,931 BGSF	2038 BGsm
ADMINISTRATION	**18,716 BGSF**	**1738 BGsm**
PUBLIC AREAS	**9,924 BGSF**	922 BGsm
SUPPORT	**26,130** BGSF	2427 BGsm
TOTAL (Initional Program)	**337,120 BGSF**	**31,319 BGsm**
OUTPATIENT CLINIC	36166 BGSF	3360 BGsm
TOTAL (Daylit Hospital)	**373,286 BGSF**	34,679 BGsm

Figure 125: Project program, developed by Perkins& Will for Montgomery Hospital and adapted for the design proposal

INPATIENT AREAS	**142,056 BGSF**	**13197 BGsm**
Medical / Surgical 36 Bed Unit I	27,984 BGSF	2560 BGsm
Medical / Surgical 36 Bed Unit II	27,984 BGSF	2560 BGsm
Medical / Surgical 24 Bed Unit	19,018 BGSF	1767 BGsm
Critical Care 24 Bed Unit	20,900 BGSF	1942 BGsm
Inpatient Dialysis (4 beds)	1,299 BGSF	121 BGsm
Women's Services & NICU:		
Post Partum & Ante Partum Unit (20 beds)	18,844 BGSF	1750 BGsm
Labor & Delivery Unit (5 beds)	19,115 BGSF	1776 BGsm
Level II Neonatal Intensive Care (8 beds)	8,211 BGSF	763 BGsm
DIAGNOSTIC AND TREATMENT:		
EMERGENCY	**25,274 BGSF**	**2348 BGsm**
Emergency Department - Primary Areas	18,059 BGSF	1778 BGsm
Emergency Department - Secondary Areas	2,907 BGSF	270 BGsm
Public / Lobby & Waiting	3,668 BGSF	341 BGsm
DIAGNOSTIC AND IMAGING	**24,634 BGSF**	**2289 BGsm**
Public Support	1,541 BGSF	143 BGsm
Staff Support	4,554 BGSF	423 BGsm
Diagnostic Imaging	19,190 BGSF	1783 BGsm
INTERVENTIONAL	**47,554 BGSF**	**4418 BGsm**
Public Support	1,071 BGSF	99 BGsm
Staff Support	5,405 BGSF	502 BGsm
Surgery Suite	28,226 BGSF	2622 BGsm
Prep/Post/PACU	12,852 BGSF	1194 BGsm

Figure 126: Detailed project program, developed by Perkins& Will for Montgomery Hospital

LIGHT DIAGNOSTIC AND TREATMENT	**21,931 BGSF**	**2038 BGsm**
Pharmacy	3,723 BGSF	346 BGsm
Laboratory	10,069 BGSF	935 BGsm
Pre-admission Testing	2,471 BGSF	230 BGsm
Diagnostic Testing	2,457 BGSF	228 BGsm
Registration	1,589 BGSF	148 BGsm
Respiratory Therapy	1,622 BGSF	151 BGsm
ADMINISTRATION	**18,716 BGSF**	**1738 BGsm**
Executive Administration	6,861 BGSF	637 BGsm
Other Administration	6,929 BGSF	644 BGsm
Medical Staff Offices Auditorium/Conference	2,265 BGSF	210 BGsm
Volunteers	858 BGSF	79 BGsm
Staff Amenities	1,803 BGSF	168 BGsm
PUBLIC AREAS	**9,924 BGSF**	**922 BGsm**
Retail	2,208 BGSF	205 BGsm
Meditation	894 BGSF	83 BGsm
Entry Lobby	6,822 BGSF	634 BGsm
SUPPORT	**26,130 BGSF**	**2427 BGsm**
Patient Transport	772 BGSF	71 BGsm
Sterile Processing	7,644 BGSF	710 BGsm
Plant Services	5,056 BGSF	470 BGsm
Housekeeping / Linen / Dock	4,632* BGSF	430 BGsm
Information Systems	3,951 BGSF	367 BGsm
Materials Management	4,075 BGSF	379 BGsm
OUTPATIENT	BGSF	BGsm
TOTAL BUILDING AREA	**18,720 BGSF**	1739 BGsm

6.3 SITE SELECTION

In contrast to the proposed greenfield site outside of the city, surrounded by suburban neighborhood, the existing Montgomery Hospital Campus and surrounding parcels were deemed appropriate and reasonable as a site for the daylight hospital proposal. Preserving green space and existing structures is one of the principles of an eco-efficient approach. Thus the demolition of residential structures on properties proposed for expansion adjoining the existing campus is intended to be minimal. The chosen site is directly east of the existing hospital campus at the corner of Fornance St and Dekalb St, connecting the site to downtown as well as to public transportation lines.

Figure 127: Proposed site and its neighborhood.

Phasing and future growth: When planning a hospital, future changes and growth needs to be considered. The flexibility to react to medical technology changes and services is therefore an important part in any hospital design. The initial program for the replacement of the medical center of Montgomery County proposes to extend the inpatient beds capacity up to 300 and double the size of the diagnostic and treatment core. The master planning and future growth of the daylight hospital is divided into three stages and is illustrated in Figure 128 with aerial views and plans. The first phase proposes to keep the existing hospital structure with the intent to reuse the space as medical offices when acute care services are relocated into the new hospital.

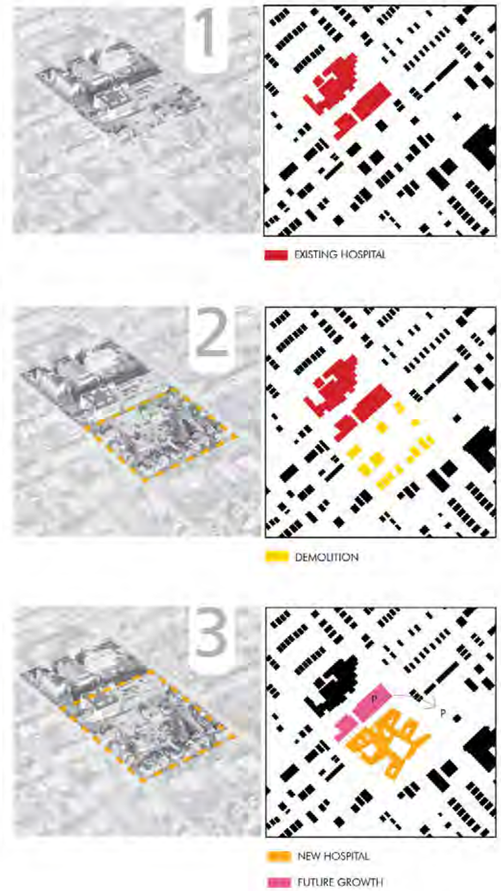


Figure 128: Site selection and phasing

The second phase describes the actual building process which includes preparing the site next to the existing hospital for the construction process by demolishing existing residental buildings (illustrated in yellow in Figure 128) and building the daylight hospital presented in this design proposal.

Phase three describes the future growth. The parking garage and medical office buildings will need to be demolished to provide space for expansion of diagnostic and treatment areas and extension of an additional patient pavilion. The main parking will be relocated across the street within short walking distance to the main entrance.

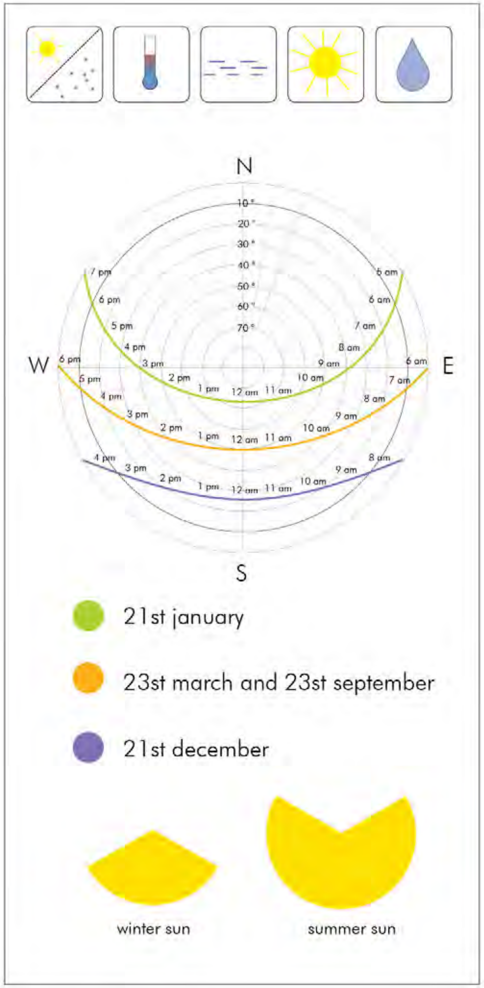


Figure 129: Climate characteristics and sun peg chart for site in Norristown.

Climate data: The climate of Norristown is characterized through seasonal change with hot and humid summers, generally mild fall and spring, and cold winter. The average annual temperature in Norristown is 54.3 F. On 23 days per year the temperature reaches 90 F or higher and on 93 days per years the temperature drops below the freezing point. During the winter, the sun rises at around 8 am at 120 degrees achieves an angle of 26° at noon and it is setting at 240 degrees around 4.30pm. At the 21st of June, the sun is rising at 60 degrees and is setting at 300 degrees. At noon the sun angle is 74° (Figure 130). These directions and angles are the foundation for the site and building development at the very beginning of the project to optimize daylighting for the proposed hospital.

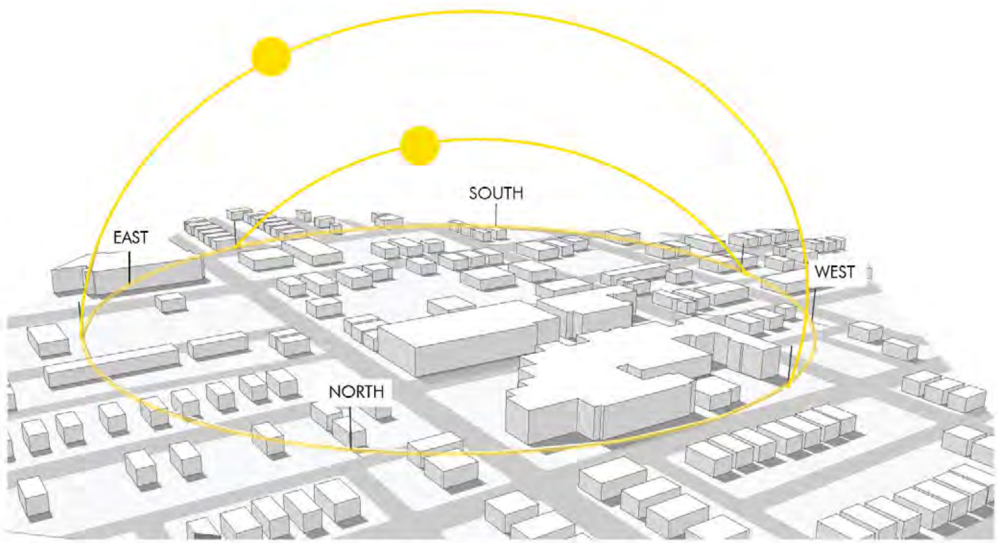


Figure 130: Proposed site with sun path throughout the day and season.

6.4 SITE AND BUILDING CONCEPTS

Building footprint and overall orientation: The overall footprint of the hospital is shifted towards a north/south orientation by 15 degrees from the urban grid. The shifted footprint creates space for pockets of green space to create a hospital settled in a park and also creates a natural buffer between the facility and its surrounding residential neighborhoods. Additionally the orientation increases the overall direct sunlight potential on the site, because it shortens the facade length facing north and increases the preferred facade length facing east and south.

1

Figure 131: Orientation and Location.

Building mass: The building mass is split into a series of smaller pavilions to provide greater flexibility for future growth. The hospital scale refers to the small scale residential neighborhood to integrate itself as a community hospital rather than separate itself as a large institutional block. This approach refers to the European community placemaking model. A courtyard in the core provides visual and physical connections to nature from public and clinical spaces. The space increases the distance between buildings and minimizes building shadows blocking the direct sunlight from others. The actual size of the courtyard is based on shadow simulations during the design process which are illustrated later in the design proposal. The courtyard is fully accessible for the public and supports the intention of the hospital to serve the community by providing space for potential activities and exhibitions on campus.

2

Figure 132: Building Mass.

3

Figure 133: Main circulation spine connects parking, new and old hospital.

4

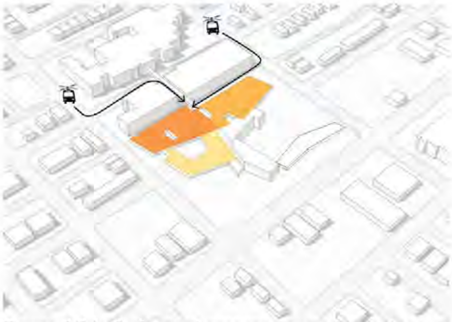


Figure 134: Perforated emergency and imaging.

5

Figure 135: Perforated surgery on first and labor&delivery with C-section on second floor.

Access and main circulation: A main circulation spine connects the existing hospital with the new one. It also addresses relocated main parking spaces later in the future growth scenario. This new parking will be connected through the retail area of the hospital. The central spine is wrapped around the central courtyard and provides visual and physical connections to the outside overlooking trees and other parts of the building to improve orientation and wayfinding for patients, visitors and staff.

Diagnostic and treatment_ emergency and imaging department: The diagnostic & treatment department (D&T) is typically built as thick building footprint, disconnecting most of the staff primary work areas from the outside. Given the increasing body of literature that visual connections to the outside and access to daylight can lower stress, increase concentration and satisfaction, the proposed emergency and imaging departments on the groundlevel, the surgery on the first and the OB/Gyn suite on the second level are highly articulated and perforated by several courtyards. The courtyards are located close to the main circulation path and at the borders of treatment blocks (see also Guideline 3: Perforated Thick Building Footprint). The D&T is located close to the existing hospital and is connected via a public circulation spine. Demolition of the existing parking garage and medical building provides future growth opportunities.

Inpatient treatment: Inpatient units are located in three pavilions. The critical care unit and labor and delivery are located in a wing, directly attached to the surgery and emergency department to minimize distance to surgery, imaging and emergency department. The general care units are located in two attached pavilions with shared amenity spaces for family and relatives and partly shared support space. Both of the inpatient pavilions integrate a courtyard in their core and are surrounded by park-pockets (see also Guideline 4: Courtyards in Inpatient Staff and Public Areas).

Outpatient: The outpatient clinic is located close to the main entrance and provides the option to enter the clinic without entering the hospital. The different medical departments are arranged along a main circulation spine, based on the concept of a departmental "shopping-front" (see also Guideline 2: Narrow Building Footprint).

Support: The main support area is located under ground and spreads along the main circulation/ distribution space.

6

Figure 136: Inpatient pavilions.

7

Figure 137: Outpatient Clinic is located close to main street to provide direct public access

8

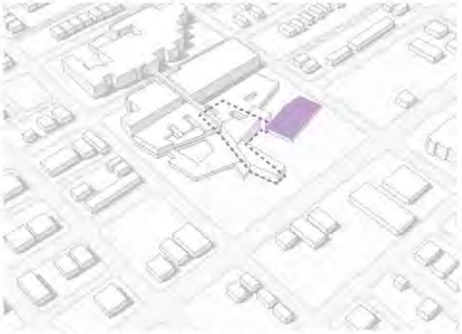


Figure 138: Support areas are mainly located in the basement under main circulation.

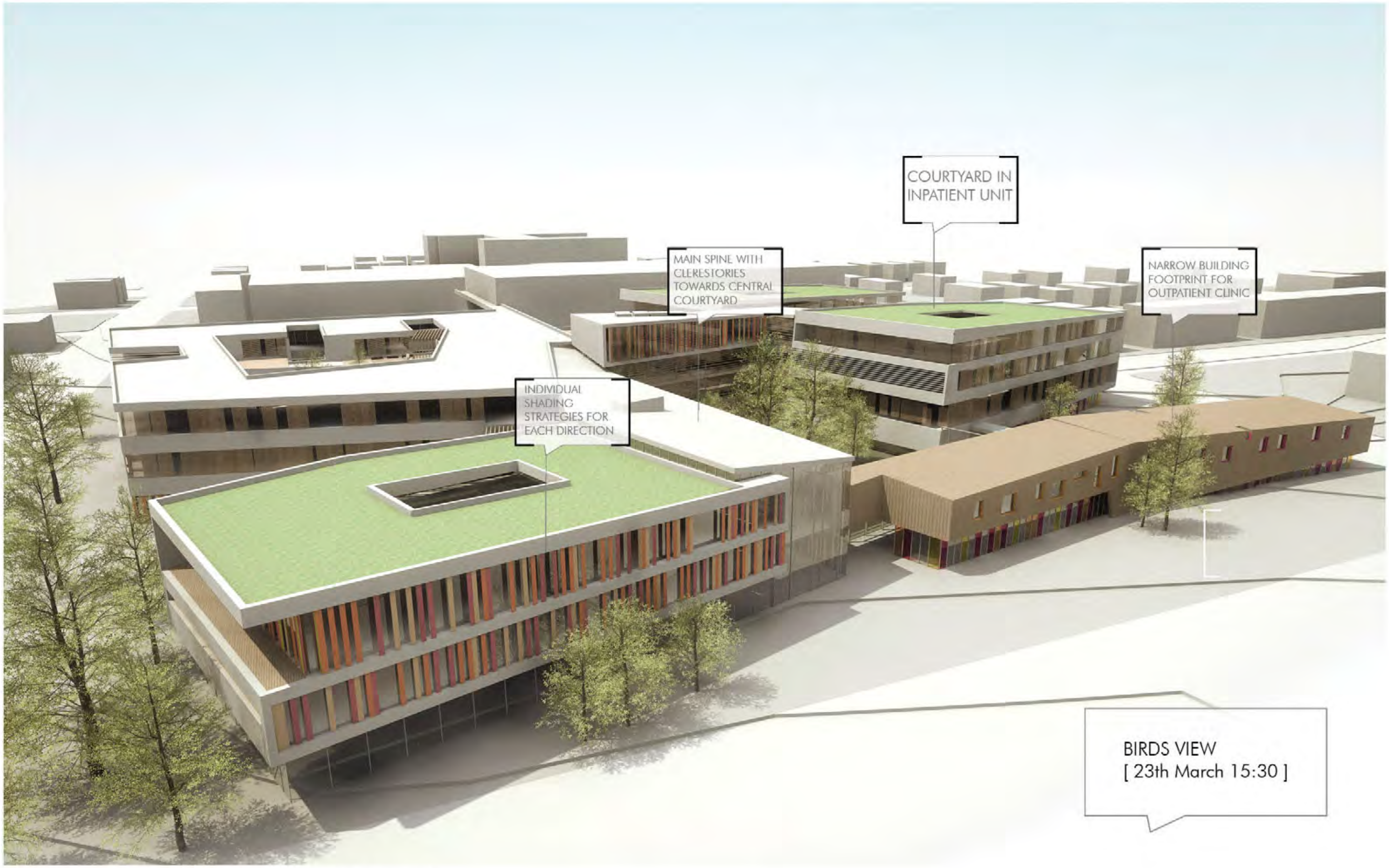


Figure 139: Birds view of the proposed daylit hospital.

Shadow Studies: It is important that the proposed hospital does not take direct sunlight from the surrounding residential neighborhood. So, the building heights are limited to four stories. Shadow simulations during the design process helped to determine the orientation of buildings and their distances to each other to ensure direct sun penetration for most of the facade. It also helped to improve sunlight penetration of the courtyards and to design their orientation and dimension according to the building height.

Figure 141: Daylight simulation for summer and fall/spring at 9am, 12am and 5pm

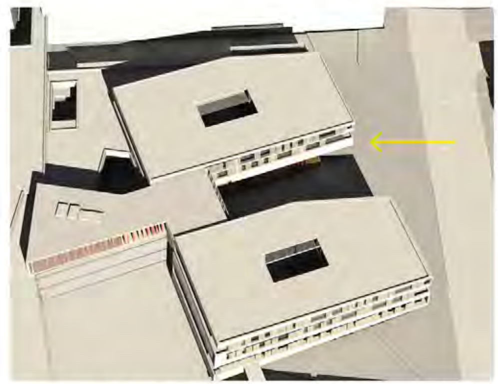


Figure 140: Daylight simulation: 23rd April, 9 am, patient rooms in upper inpatient tower receive direct morning sun. Only parts of the surgery and imaging are cast from shadow from lower inpatient unit pavilion.

- Main Public Courtyard
- Courtyard Inpatient Units
- Courtyard Clinic
- Courtyards Diagnostic and Treatment 1
- Courtyard Critical Care/ Labor and Delivery 2

Figure 142: Perforated building footprint integrating several courtyards.

Green spaces: Providing visual and physical connections to nature at all scales, especially for a hospital in an urban context is one of the main design drivers for the design proposal of this hospital. Overlooking natural scenes have a range of positive influence on patient's recovery, stress levels and satisfaction. Therefore the hospital integrates several courtyards with different dimension within and between their departments. Also, most of the roofs are planted to provide a pleasant view and some of the roofs are accessible from public and inpatient areas.

Figure 143: Groundfloor with site context.

Facade design: The concept for the facade is dependant of the functional use of the space. For instance, the exterior shading systems for the facade of inpatient areas or offices spaces are individually adjustable based on personal preference. Shadings in public and non-inpatient areas such as circulation space are either fixed or automatically controlled. Based on the developed concepts in Chapter 5.2 Daylighting Guideline 5: Shading, each facade orientation has different shading concepts to address the changing position of the sun throughout the day and season.

The facades of non-inpatient areas facing east and west employ vertical louvers to control incoming light. These louvers can be turned perpendicular to the facade to let direct sunlight pass, half open to diffuse the light and closed (Figure 144) to block the sun.

Non-inpatient areas facing south are equipped with horizontal louvers to protect the interior space against excessive heat gain and glare during hot seasons. The distances between the louvers increases towards the field of view (up to 15 inches/ 400mm) to improve the view out for building occupants and decrease down to 6 inches/ 150mm in the space above and below that field (Figure 145).

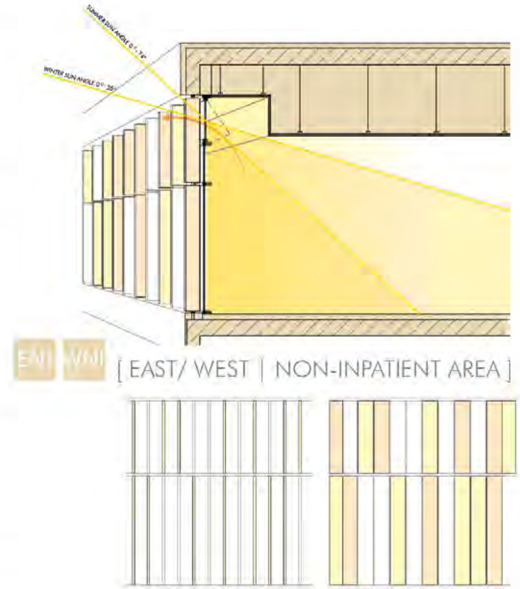


Figure 144: Shading concept for non-inpatient areas facing east or west.

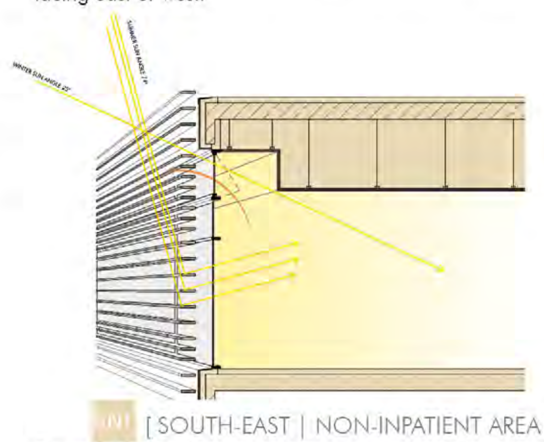


Figure 145: Shading concept for non-inpatient areas facing south.

Facade concepts for inpatient area are split in three layers. The first exterior layer, individually adjustable by the patient, blocks and redirect the sun to avoid heat gain or glare, the low-emission glazing filters part of the UV-light and helps against heat gain and heat lost during the winter. The interior layer, the curtain or blinds can be used to darken the room. Sliding shutters on eastern or western facades block the sun or let sun in when desired. The shutters can be made out of wood, perforated metal or printed fabric on a frame.

There are two proposed concepts for southern facades: the first option provides a private balcony, accessible from each patient room. The overhang from the balcony above blocks the summer sun and during winter sliding shutters can be used to control the sunlight. The reflecting surface of the upper interior frame of the window redirect the incoming light against the ceiling to increase the daylight distribution deep into the interior, supported by the raised ceiling along the perimeter. The second

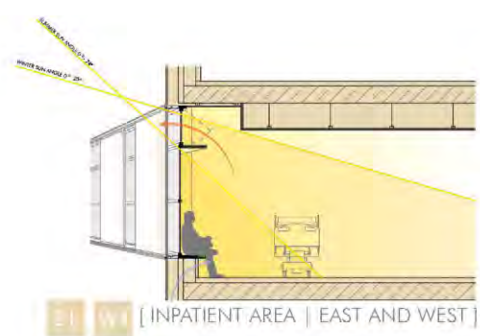


Figure 146: Shading concept for inpatient areas facing east and west.

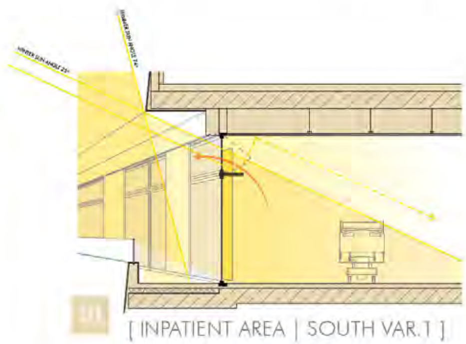


Figure 147: Shading concept for inpatient areas facing south with balcony.

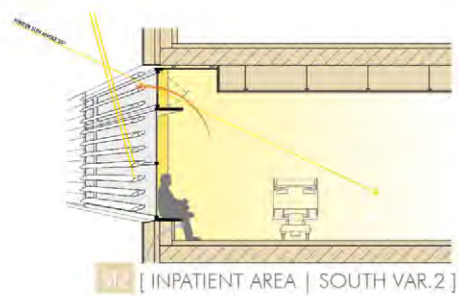


Figure 148: Shading concept for inpatient areas facing south.

proposed facade for inpatient area facing south are horizontal louvers. Their position is adjustable as needed to block, redirect or diffuse the incoming light. Similar to the proposal for eastern and western facade the window sill is lowered down to 16inches (400mm) above the floor to provide a view out for patients in their beds as well as provide an opportunity for visitors to rest.

Figure 149: Floorplan level one illustrating the perforated building footprint of PACU and Surgery department (with facade matrix for shading concepts)

6.5 FOCUS AREA: NON-INPATIENT AREA | PUBLIC SPACE

Figure 150: Clerestories on southern side of circulation spine provide direct sunlight for the space.

To improve orientation and wayfinding all main circulation areas have visual connections to the outside overlooking other parts of the building. Most parts of the public circulation spine faces north towards the courtyard and is fully glazed. Clerestories on the southern facade provide direct sunlight into the space as illustrated in Figure 150 (see also Guideline 6: Skylights and Clerestories). Clerestories on ground floor of public space provide views from the interior space and support clinic-without-walls concept. Glass frittings provide privacy and sun control where needed. Public spaces as retail and non-inpatient areas such as office spaces are designed as narrow building footprints to promote views to nature and natural ventilation for all

Figure 151: Main circulation spine connects parking, new and old hospital together

Figure 152: Main entrance.

occupied areas (see also Guideline 2: Narrow Building Footprint). Their facade is designed with single openings. All windows can be opened by building occupants to naturally ventilate the building during temperate seasons.

Figure 153: Medical office/ outpatient building with narrow building footprint.

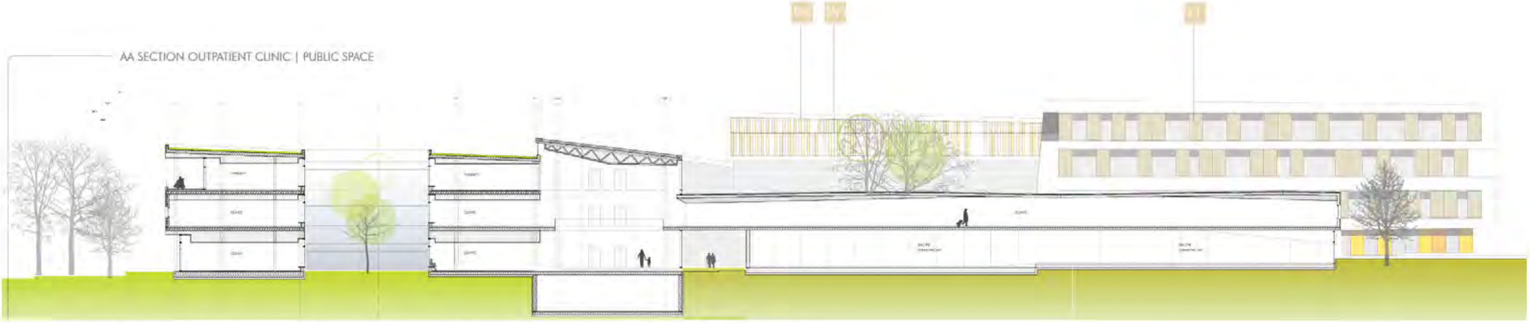


Figure 154: Section through outpatient clinic, circulation spine and medical offices/ retail.

Figure 155: Section through diagnostic and treatment: emergency, PACU and NICU.

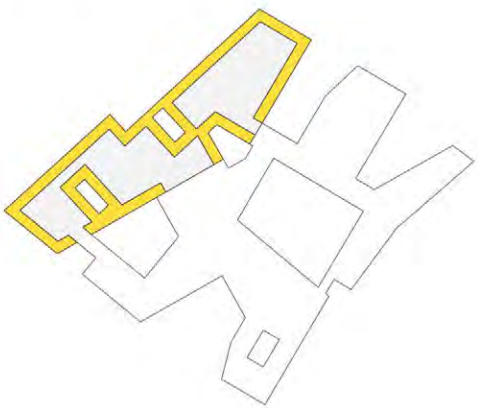


Figure 156: Diagnostic and treatment: daylight area

6.6 FOCUS AREA: DIAGNOSTIC AND TREATMENT AREAS

To increase daylight availability within the diagnostic and treatment areas, the department is built as an articulated and perforated form instead of a square to increase perimeter wall. Planned enclosed courtyards provide daylight for core areas. With these perforations the daylight area of the diagnostic and treatment departments are 48 % higher than the area within 15' of hypothetical perimeter formed by a square of the actual building floor area. (Calculation based on Green Guide for Healthcare, see also Chapter 3, section 3.3: Environmental Responsibility)

Figure 157: Diagnostic and treatment, first level.

Wayfinding: Main circulation paths within the department have visual connections to the outside to improve orientation and wayfinding. They are either located along the buildings perimeter or along the enclosed courtyards as illustrated in Figure 157 and Figure 158.

Patient satisfaction: Most waiting spaces in the D&T are located on the perimeter wall and have visual and some of them physical access to the outside (Figure 158).

Figure 158: Main circulation and waiting spaces within emergency and imaging, ground level.

Staff satisfaction, stress and performance: Most primary staff working areas in the diagnostic and treatment department (D&T) have access to daylight and views to the outside within 15-20 feet of their primary work station. For instance, 15′ x 30′ courtyards between two PACU pods provide daylight accessibility for staff as well for recovering patients as illustrated in Figure 155. In addition, the courtyard between the D&T and the ICU and Labor and Delivery provides a pleasant view, overlooking trees. To ensure optimized visual performance, especially crucial for the work needed in urgent care, shading devices diffuse the incoming light to reduce glare and distraction (Figure 159).

Figure 159: Primary work station in PACU with direct access to daylight and views to nature.

6.7 FOCUS AREA: INPATIENT UNITS

Patient's Recovery | Healing Process: Inpatient care units are mainly located on the second and third level of the hospital to optimize access to sunlight and improve the quality of view, overlooking the parks and city. The orientation and shape of the

Figure 161: Floorplan level two.

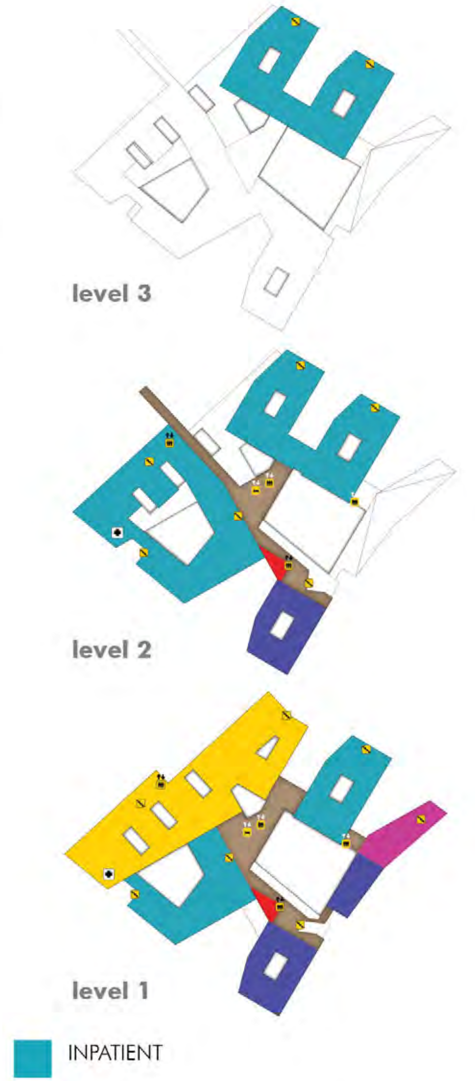


Figure 160: Departmental planning: Inpatient units.

PATIENT ROOMS EAST-SOUTH

PATIENT ROOMS SOUTH-WEST

PATIENT ROOMS WEST-NORTH

Figure 162: Inpatient unit, floorplan level 3.

inpatient units are designed to avoid northern facing patient rooms without direct sunlight and is illustrated in Figure 162. The majority (44 out of 96) inpatient rooms in general care units face southeast with sunlight exposure during the morning. 33 patient rooms are oriented south/ south-west and 19 patient rooms are located on the north-western side. East and south facing is, according to an increasing body of evidence, the direction with best health outcomes, shortest length of stay, lowest mortality rate and lowest experience of pain (see chapter 2: Daylight and Health, 2.1 Improved Health Outcomes).

Figure 163: Roof terrace inpatient unit.

Visual and physical access to the outside: All patients rooms have views to nature, overlooking trees through pockets of greens. 16 patient rooms have direct access to the roof terrace or balconies as illustrated in Figure 163. The roof terrace are also accessible through the public space of the inpatient units and provide places of respite for visitors and staff. For instance a roof terrace in between the delivery and postpartum inpatient unit provides outside waiting space for relatives and visitor (Figure 164).

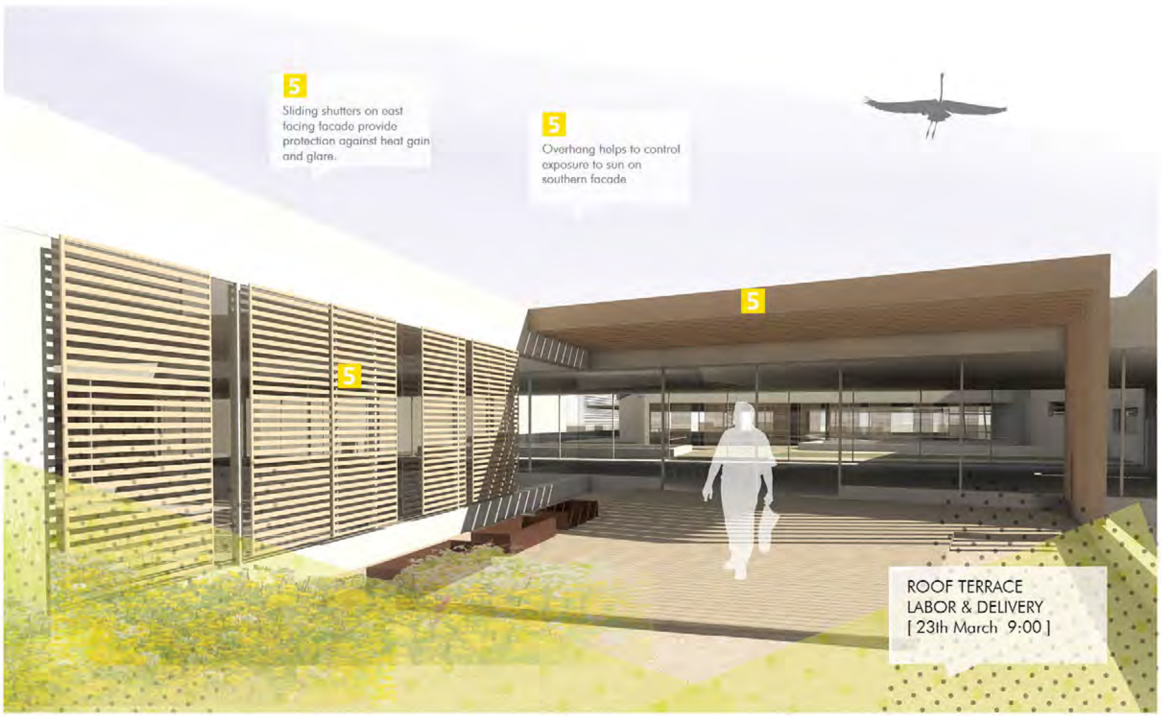


Figure 164: Roof terrace between labor and delivery and post partum inpatient unit provide outside space for waiting relatives.

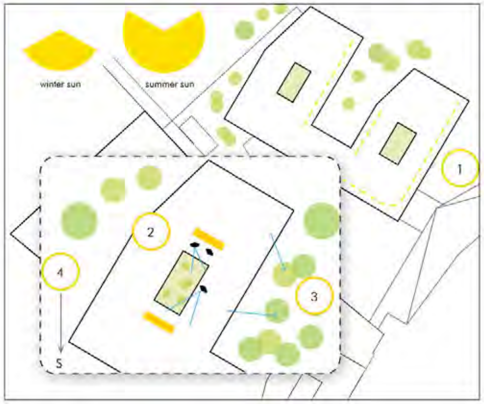


Figure 165: Courtyards and views to nature design principles.

Staff Satisfaction | Stress & Productivity: All primary staff working areas have access to daylight and views to the outside through central courtyards. The courtyards in the general inpatient units are rectangular and oriented with the longer dimension along the north-south axis (Figure 165). This orientation increases the daylight availability for the lower levels of the building (see also Guideline 1: Orientation and Location and Guideline 4: Courtyards in Inpatient Staff and Public Areas).

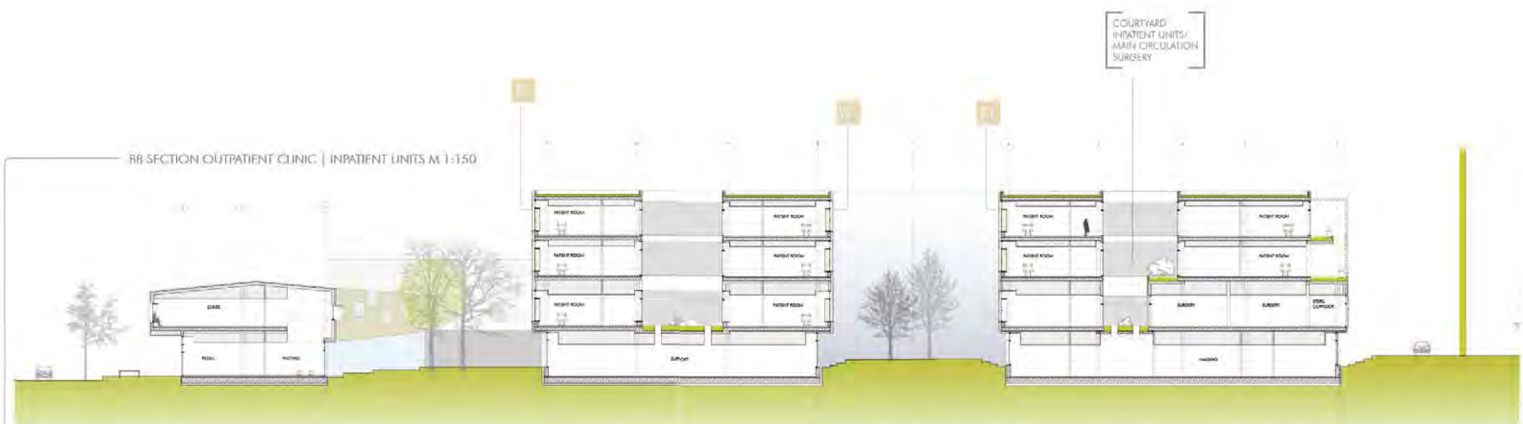


Figure 166: Section through inpatient pavilions and courtyard

7 CONCLUSION

A growing body of literature indicates the importance of having access to daylight and views to the outside for human health and wellbeing. By providing the connection to daylight positive health outcomes, positive experience, increased satisfaction and increased performance could be linked to the effort. In addition, daylighting, if designed properly, reduces energy consumption. Yet, it may be more costly initially to build an articulated and/ or perforated building with much more daylight availability than a thick building footprint. However, this investment will result in long term savings and incomes such as lowering staff error related costs, lowering energy costs, lowering staff turnover rates, and increasing patient loyalty and satisfactory.

Despite the values daylighting brings to the built environment, no current building code in the US makes access to daylight for building occupants mandatory. Therefore, performance oriented requirements regarding daylighting and views are needed to be developed and added to the recommendations. The fact that most objectives are linked to certain conditions which can be either measured or expressed, illustrates potential areas for future research and development of performance benchmarks. Incorporated into building guidelines performance benchmarks could be effective in giving guidance how to incorporate daylighting design ideas in different functional areas of a hospital.

In addition to the performance benchmarks, concluded from the literature review, real world applications gave guidance for developing daylighting guidelines which were used as basis for the design proposal. The study of best practices around the world included site visits in Australia, the US, and Europe. Additionally, shadow simulations, and the review of accreditation programs directed the proposed hospital design.

The design proposal illustrates an application of developed daylight guidelines for future hospitals in particular: how to reformulize future building footprint and typology to increase building perimeter and thus daylighting availability. The following main

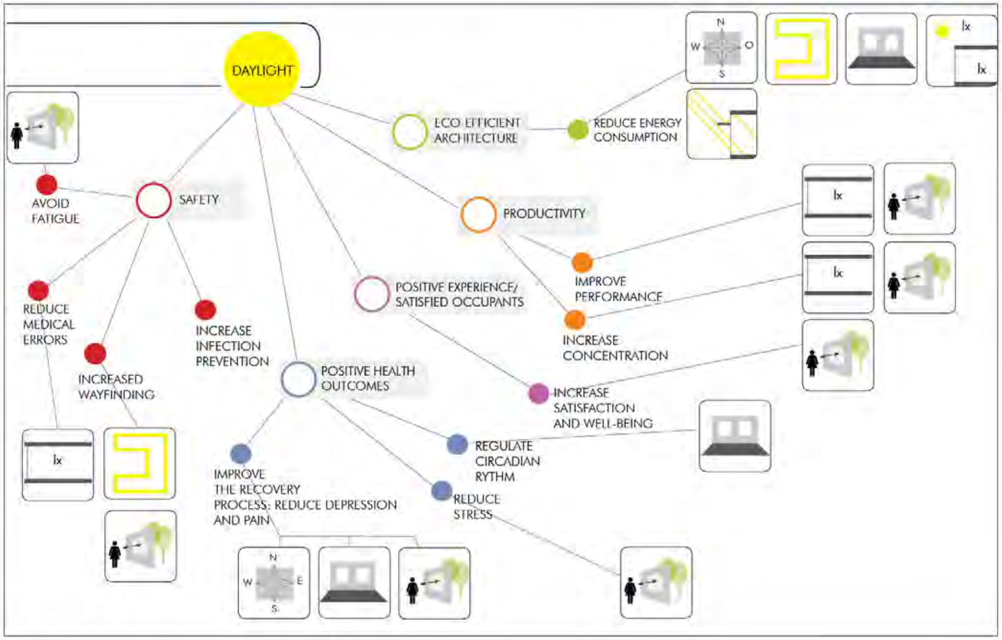


Figure 167: Map linking goals to objectives to performance benchmarks.

focus areas were established during the design process: 1) the orientation to optimize sun exposure for building occupants, 2) the development of appropriate sun control, 3) the location and dimension of planned enclosed courtyards, and 4) the use of roof surfaces to provide visual and physical access to the outside.

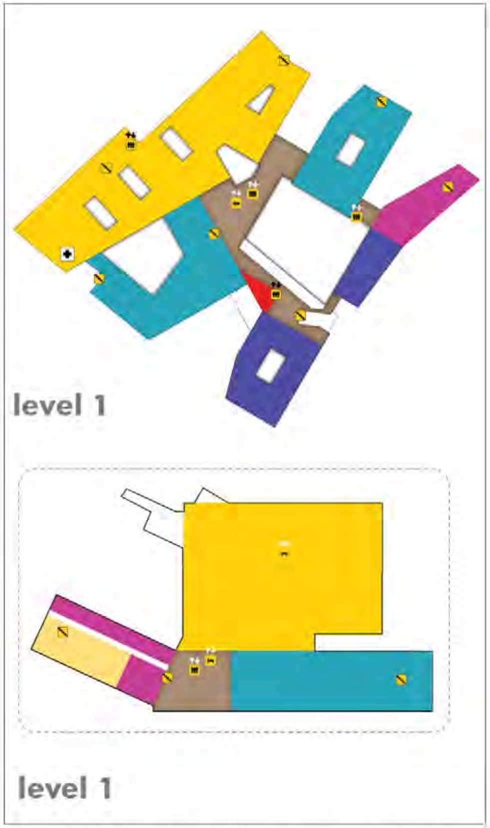


Figure 168: Departmental planning: upper diagram: daylight hospital, lower diagram: conventional hospital as built

Departmental Planning and Comparison: Despite the first assumption that an articulated building footprint would increase overall travel distances, the comparison of travel distances in the daylit hospital with the travel distances in the proposed conventionally built hospital with the same program, indicates that the travel distances can be even lower. Only the food delivery from the kitchen to the farthest patient room was longer (554 feet in case of the daylit hospital and 508 feet in case of the conventionally built). All other scenarios, illustrated in Figure 169, have shorter travel distances between start and end point. Especially the travel distance between the farthest patient room to the farthest surgery was significantly shorter in the proposed hospital (442 feet than 817 in the conventionally built proposed design).

This leads to the assumption that articulated building footprints do not necessary increase travel distances between and within departments.

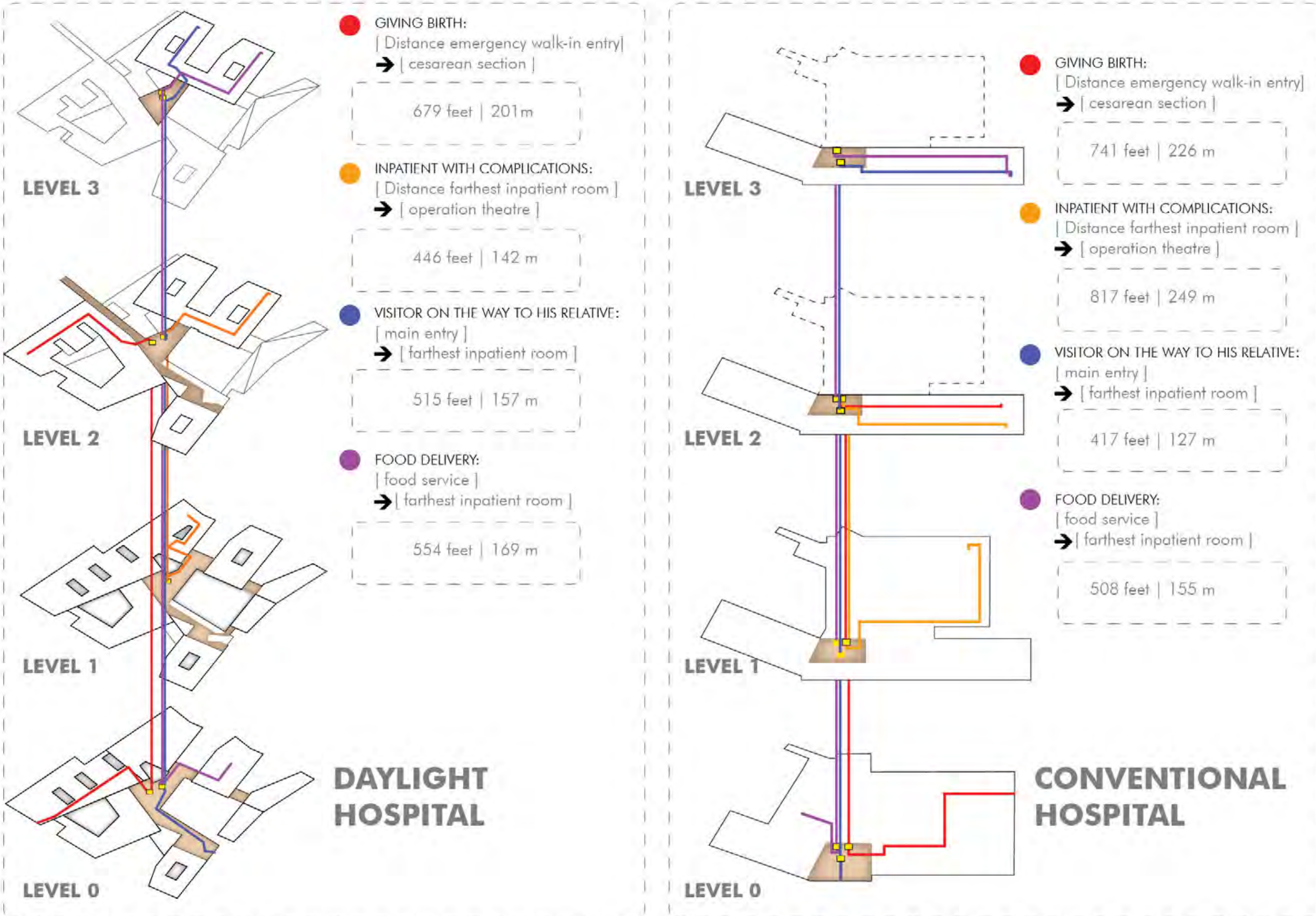
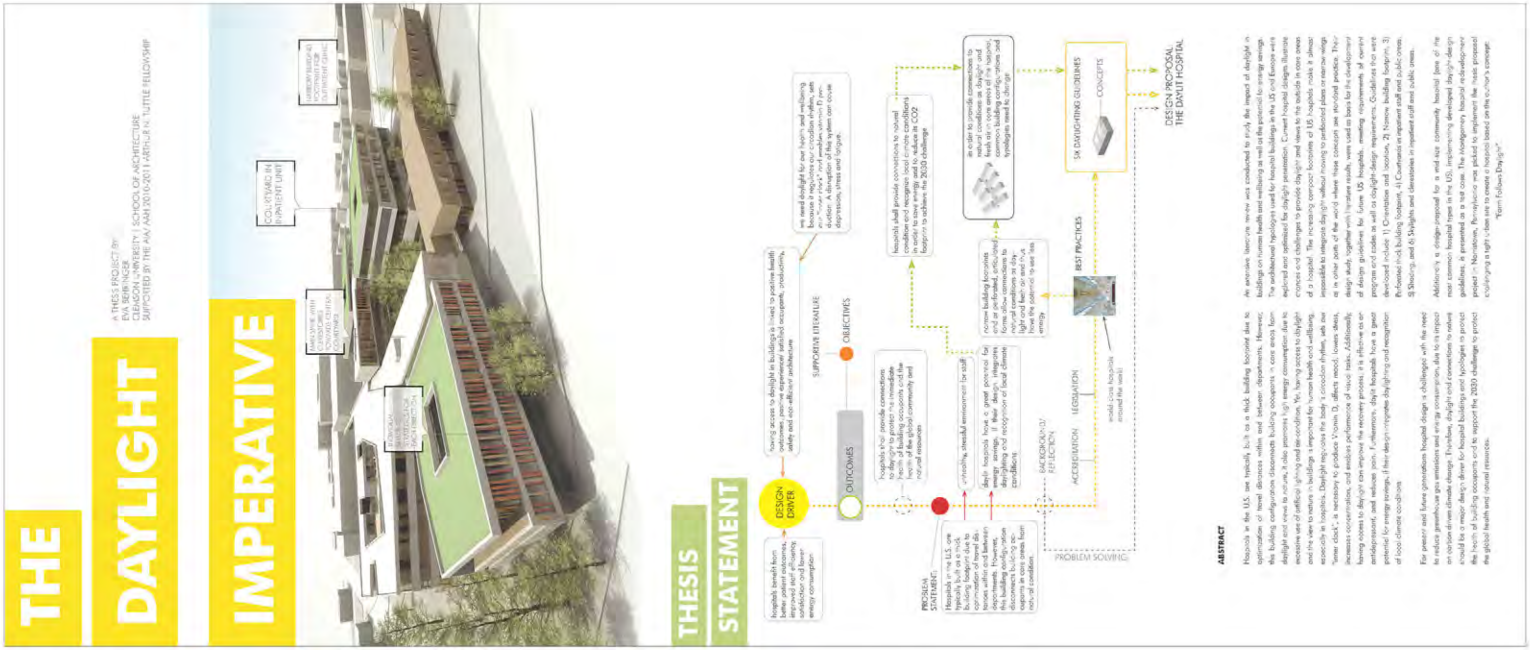


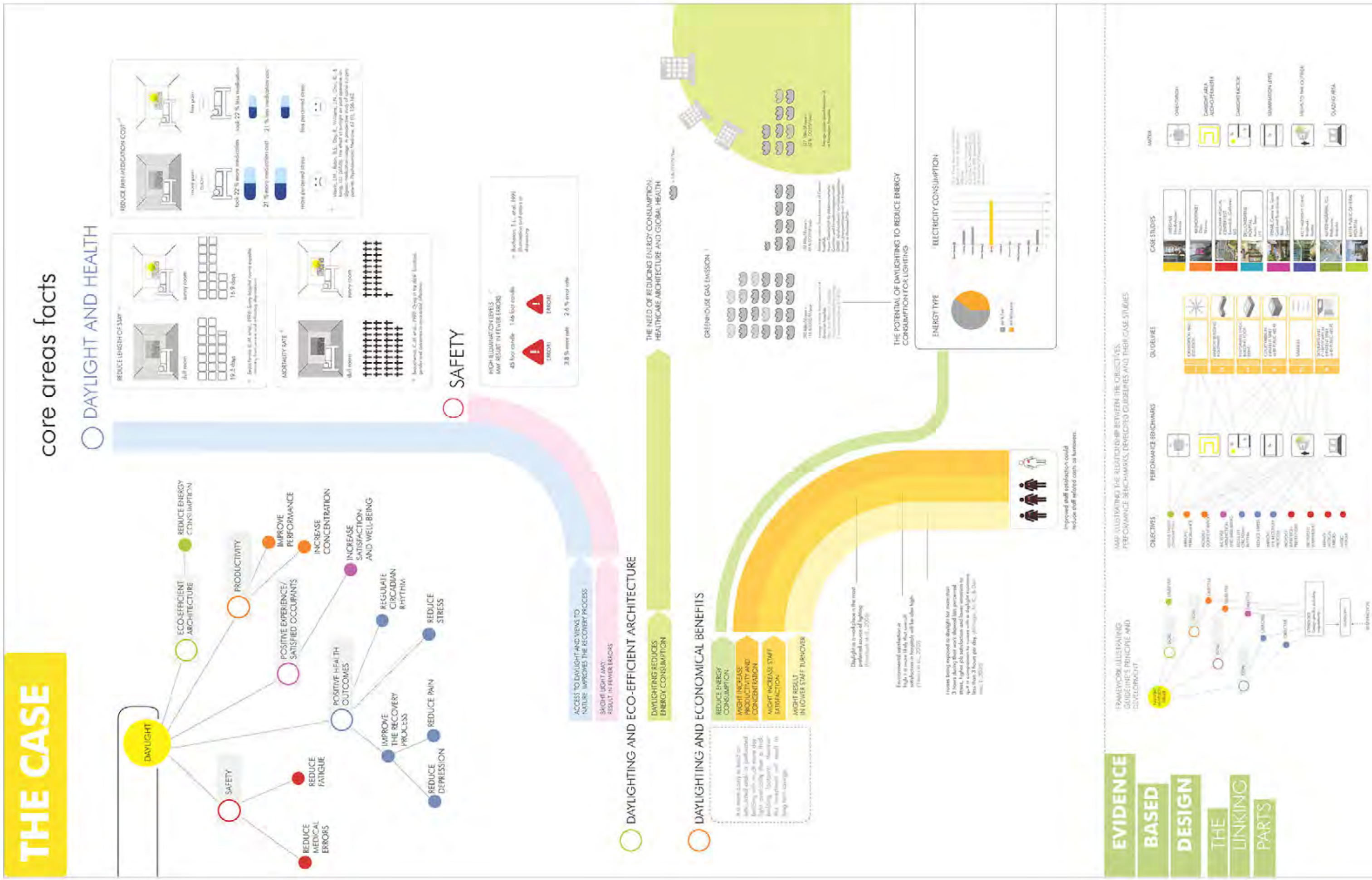
Figure 169: Spreadsheet: travel distances comparison between daylight and conventional hospital.

Figure 170: Spreadsheet: daylight area comparison

APPENDICES



Presentation board 1



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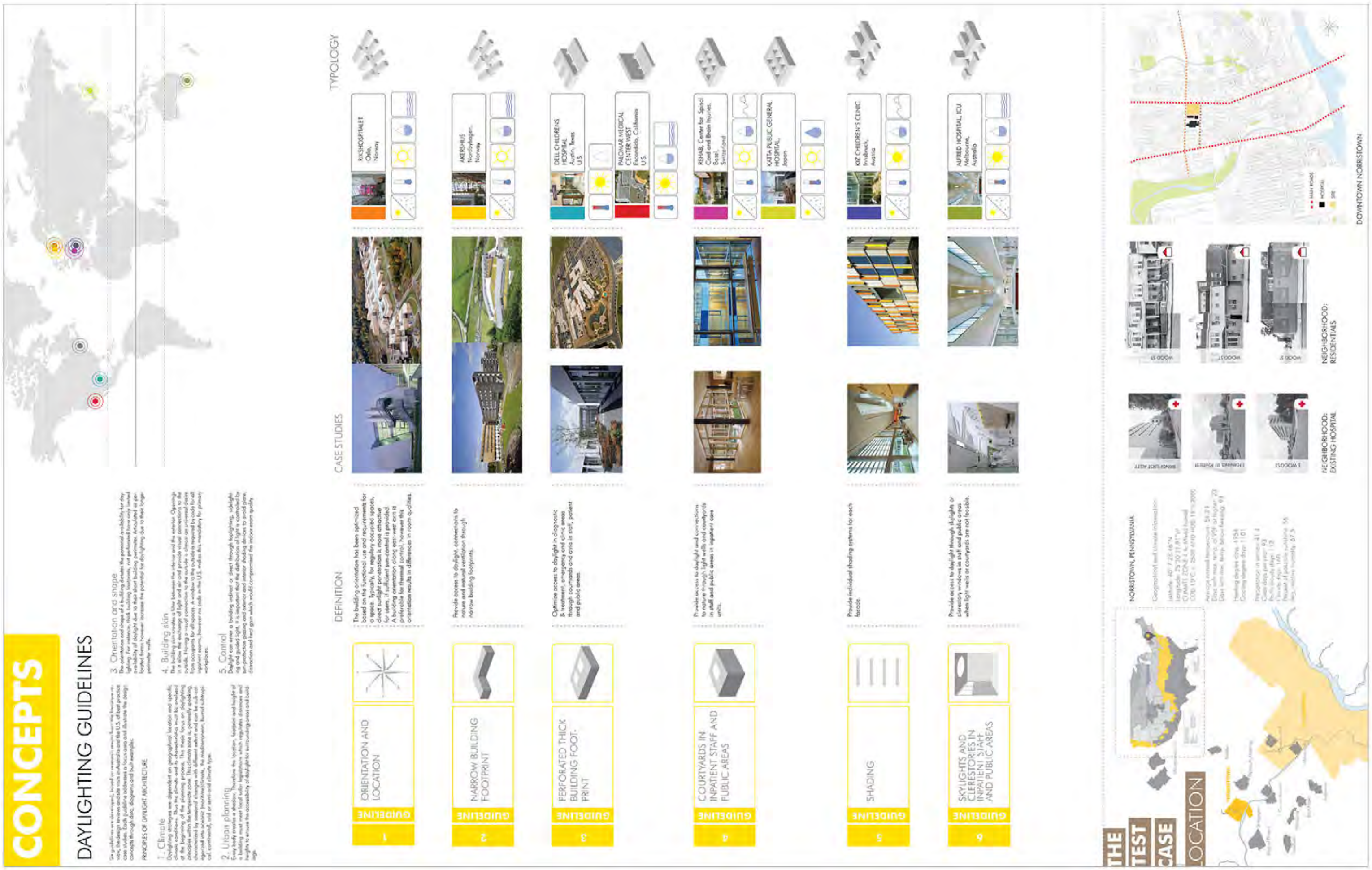

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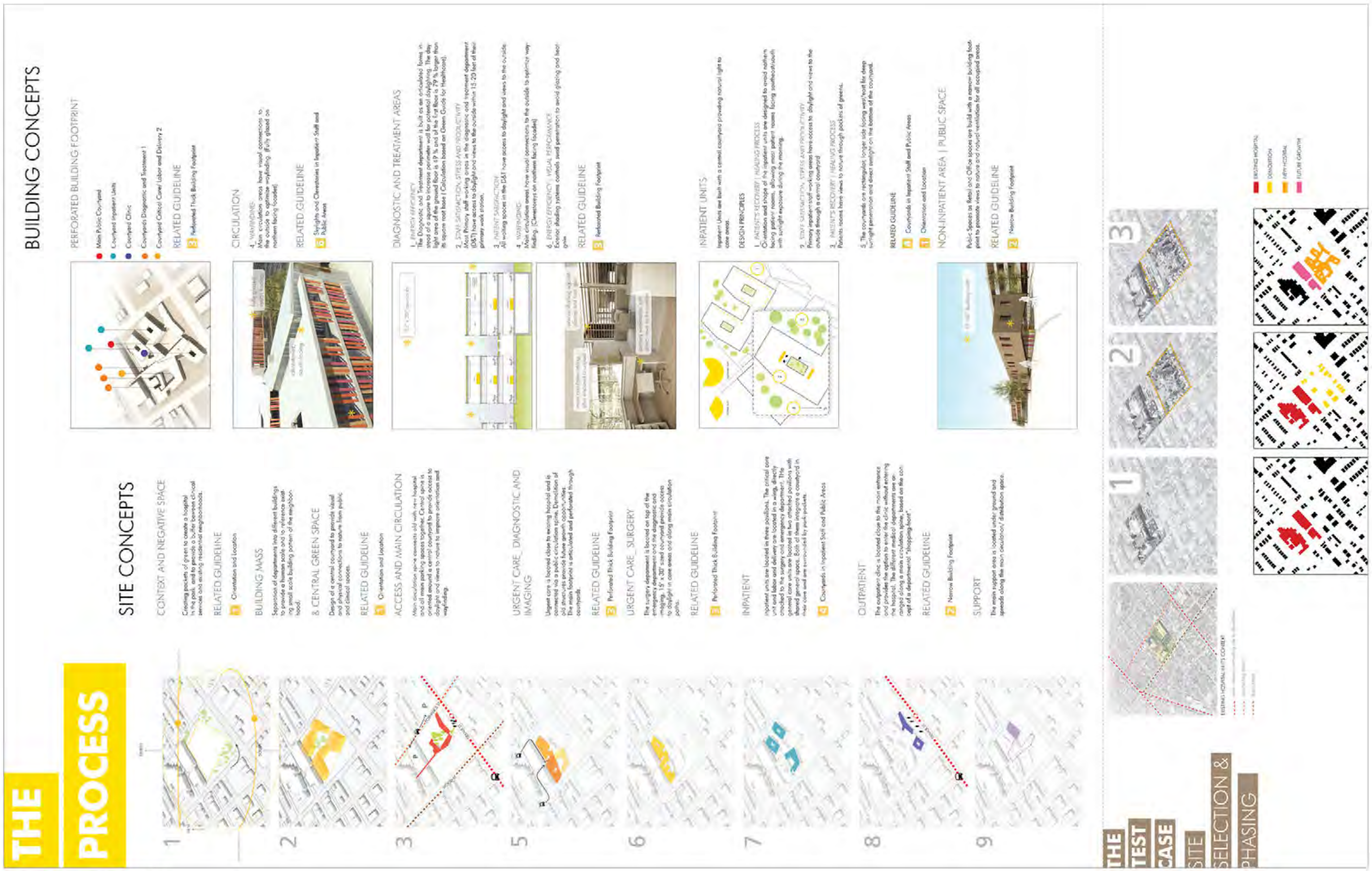

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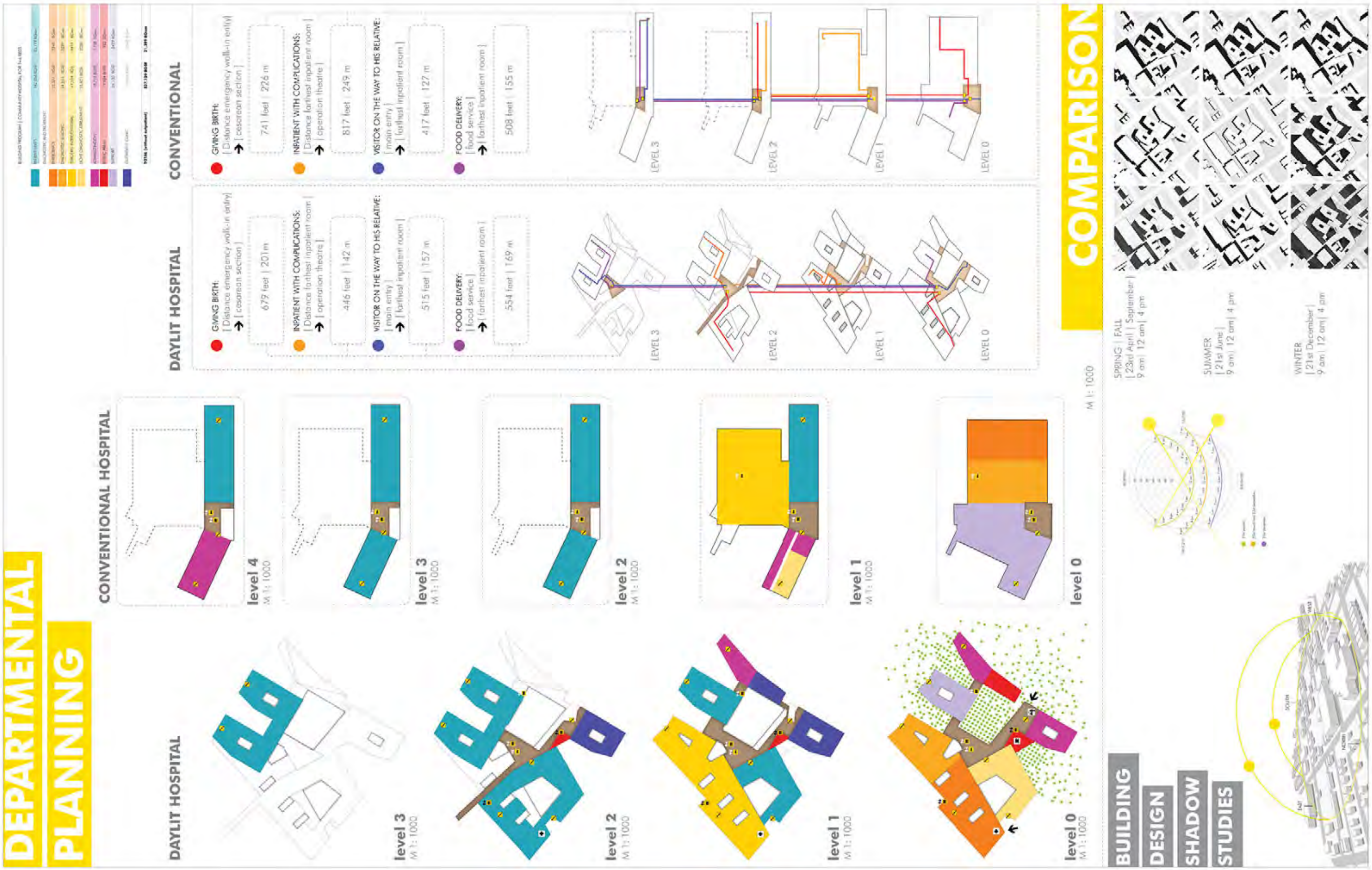

Presentation board 5

Presentation board 6

Presentation board 7

Presentation board 8

Presentation board 9


Final Model M 1:1000

FIGURES CREDITS

Title Page: Children's Hospital Heidelberg, Germany, Architects: Nickl & Partner, Munich
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02: Map illustrating the impact of daylight on health, wellbeing, safety and sustainability
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111: Horizontal blinds and redirecting panels for exterior sun control
http://www.howardalanarchitects.com/HOWARD%20ALAN%20ARCHITECTS_pliki/projects/pv.htm, as of 03.31.11.

112: Sun control strategies diffuse daylight distribution: clerestory facing north (1) and clerestory with redirecting blinds (2)
Behringer, 2011

113: Single skylight, Birthing Center, Gastonia, SC
Simpson, D. 2009

114: Clerestories above nurse station of ED, St. Mary's Hospital, Walla Walla, US
http://www.djc.com/news/ae/11163008.html, as of 04.25.11.

115: Deep sun penetration through skylight, mirrors and sloped walls, Knittelfeld Hospital, Austria
http:\\www.faschundfuchs.com, as of 04.25.11.

116: Section through inpatient unit, Knittelfeld Hospital, Austria
http:\\www.faschundfuchs.com, as of 04.25.11.

117: High clerestories in Intensive Care Unit for effective daylight penetration,
Alfred Hospital, Melbourne, Australia
Behringer, 2011

118: Effective daylight penetration, calculation of skylight spacing and
qualification as daylight area according to GGHC
Behringer, 2011

119: Climate zone 4
ASHRAE Climate Zones – U.S.

120: Unbundled hospital typology with patient tower and typically thick D&T block
Behringer, 2011

121: City of Norristown 6 miles (10 km) northwest of the city limits of Philadelphia
Behringer, 2011

122: Existing Hospital of Montgomery County
Behringer, 2011

123: Location of existing hospital
Behringer, 2011

124: Replacement hospital on greenfield site, rendering, site plan and floorplan level
From Presentation: Urban Analysis Project by Perkins & Will at Clemson University, 09.03.2009

125: Project program, developed by Perkins& Will for Montgomery Hospital
and adapted for the design proposal
From Presentation: Urban Analysis Project by Perkins & Will at Clemson University, 09.03.2009

126: Detailed project program, developed by Perkins& Will for Montgomery Hospital
From Presentation: Urban Analysis Project by Perkins & Will at Clemson University, 09.03.2009

127: Proposed site and its neighborhood
Behringer, 2011, birds view: Microsoft

128: Site selection and phasing
Behringer, 2011, birds view: Microsoft

129: Climate characteristics and sun peg chart for site in Norristown
Behringer, 2011

145: Shading concept for non-inpatient areas facing south
Behringer, 2011

146: Shading concept for inpatient areas facing east and west
Behringer, 2011

147: Shading concept for inpatient areas facing south with balcony
Behringer, 2011

148: Shading concept for inpatient areas facing south
Behringer, 2011

149: Floorplan level one illustrating the perforated building footprint of PACU and Surgery department
Behringer, 2011

150: Clerestories on southern side of circulation spine provide direct sunlight for the space
Behringer, 2011

151: Main circulation spine connects parking, new and old hospital together
Behringer, 2011

152: Main entrance
Behringer, 2011

153: Medical office/ outpatient building with narrow building footprint
Behringer, 2011

154: Section through outpatient clinic, circulation spine and medical offices/ retail
Behringer, 2011

155: Section through diagnostic and treatment: emergency, PACU and NICU
Behringer, 2011

156: Diagnostic and treatment: daylight area
Behringer, 2011

157: Diagnostic and treatment, first level
Behringer, 2011

158: Main circulation and waiting spaces within emergency and imaging, ground level
Behringer, 2011

159: Primary work station in PACU with direct access to daylight and views to nature
Behringer, 2011

LITERATURE CITIED (ANNOTED BIBLIOGRAPHY)

REGULATES CIRCADIAN RHYTHM:

Terman, J. S., Terman, M., Lo, E.-S., & Cooper, T. B. (2001). Circadian time of morning light administration and therapeutic response in winter depression. Archives of General Psychiatry, 58(1), 69–75.

Objective: A possible mechanism of action for the antidepressant response to light- phase advances of the circadian clock was investigated. In the study the onset of melatonin secretion was measured before and after light treatment in the morning and evening.

Methods: Quantitative Survey: Plasma melatonin was sampled in 42 patients with seasonal affective disorder, in the evening or overnight while depressed and after 10 to 14 days of light therapy (10 000 lux for 30 minutes) when symptoms were reassessed.

Results: Morning light produced phase advances of the melatonin rhythm, while evening light produced delays, the magnitude depending on the interval between melatonin onset and light exposure, or circadian time (morning, 7.5 to 11 hours; evening, 1.5 to 3 hours).

The antidepressant effect of light is potentiated by early-morning administration in circadian time, optimally about 8.5 hours after melatonin onset or 2.5 hours after the sleep midpoint.

Limitations: Winter depression

Figueiro, M. G., Rea, M. S., Stevens, R. G., Rea, A. C. (2002). Daylight and productivity - a possible link to circadian regulation. The Lighting Research Office of the Electric Power Research Institute (2002), 185-193.

IMPROVE RECOVERY PROCESS: REDUCE DEPRESSION

Beauchemin, K..M. & Hays, P. (1996). Sunny hospital rooms expedite recovery from severe and refractory depressions. Journal of Affective Disorders, 40 (1-2), 49-51

Methods: The rooms in the psychiatric inpatient unit are so placed that half are bright and sunny and the rest are not.

Results: An analysis of the lengths of stay of depressed patients in sunny rooms with those of patients in dull rooms shows that those in sunny rooms had an average stay of 16.9 days compared to 19.5 days for those in dull rooms, a difference of 2.6 days (15%): $P < 0.05$.

Beauchemin, K. M., & Hays, P. (1998). Dying in the dark: Sunshine, gender and outcomes in myocardial infarction. Journal of the Royal Society of Medicine, 91(7), 352–354.

Objective: To study the impact of sunlight on the mortality of patients with myocardinal infarchtion.

Methods: The paper reports a natural experiment that took place in a cardiac intensive care unit over four years ending March 1996.

Results: The interpretation of the data show a difference in outcomes between patients with MI who were treated in certain parts of our CICU, sunny rooms being associated with better outcomes:

Outcomes of those treated in sunny rooms and those treated in dull rooms were retrospectively compared for fatal outcomes and for length of stay in the CICU. Patients stayed a shorter time in the sunny rooms, but the significant difference was confined to women (2.3 days in sunny rooms, 3.3 days in dull rooms). Mortality in both sexes was consistently higher in dull rooms (39/335 dull, 21/293 sunny).

The authors conclude that illumination may be relevant to outcome in MI, and that this natural experiment merits replication.
Limitations: Only patients with myocardinal infarction were evaluated for the interpretation.

Benedetti, F., Colombo, C., Barbini, B., Campori, E., & Smeraldi, E. (2001). Morning sunlight reduces length of hospitalization in bipolar depression. Journal of Affective Disorders, 62(3), 221–223.
Objective: Bright artificial light improves non-seasonal depression. Preliminary observations suggest that sunlight could share this effect.
Method: (quantitative survey) Length of hospitalization was recorded for a sample of 415 unipolar and 187 bipolar depressed inpatients, assigned to rooms with eastern (E) or western (W) windows.
Results: Bipolar inpatients in E rooms (exposed to direct sunlight in the morning) had a mean 3.67-day shorter hospital stay than patients in W rooms. No effect was found in unipolar inpatients.
The conclusion of the study is that natural sunlight can be an underestimated and uncontrolled light therapy for bipolar depression.
Limitations: Unipolar and bipolar depression

Lewy, A. J., Bauer, V. K., Cutler, N. L., Sack, R. L., Ahmed, S., Thomas, K. H., et al. (1998). Morning vs. evening light treatment of patients with winter depression. Archives of General Psychiatry, 55(10), 890–896.
Objective: The study assesses light-exposure schedules in both crossover and parallel- group comparison because of the hypothesis that morning light should more antidepressant than evening light.
Methods: Part of the study was quantitative survey, the other part qualitative survey.
Results: Morning light phase-advanced the dim-light melatonin onset and was more antidepressant than evening light, which phase-delayed it. The results should help establish the importance of circadian (morning or evening) time of light exposure in the treatment of winter depression. The authors recommend that bright-light exposure be scheduled immediately on awakening in the treatment of most patients with seasonal affective disorder.
Limitations: Only patients with winter depression took part in the study.

Wallace-Guy, G., Kripke, D., Jean-Louis, G., Langer, R., Elliott, J., & Tuunainen, A. (2002). Evening light exposure: Implications for sleep and depression. Journal of the American Geriatrics Society, 50(4), 738–739.

Objective: To examine whether dim illumination in the evening is a factor in sleep disturbances of aging, depression, and circadian phase advance.
Methods: Experimental research.
Results: Illumination in the 4 hours before bedtime was quite dim: median 24 lux. Nevertheless, evening light exposure was not significantly related to sleep amount (in bed or out of bed) sleep efficiency, sleep latency, wake within sleep, or mood. In contrast, the overall amount of light throughout the 24 hours was negatively correlated with sleep latency, wake within sleep, and depressed mood. Low evening lighting does not appear to be a crucial factor in sleep and mood disturbances of aging, but overall lighting may contribute to these disturbances.
Limitations: Only female patients with postmenopausal depression took part in the study.

Oren, D. A., Wisner, K. L., Spinelli, M., & Epperson, N. (2002). An open trial of morning light therapy for treatment of antepartum depression. American Journal of Psychiatry, 159(4), 666.

Objective: Exploring the use of morning bright light therapy for antepartum depression.

Methods: Experimental research

Results: The results were that after 3 weeks of treatment, mean depression ratings improved by 49%. Benefits were seen through 5 weeks of treatment. There was no evidence of adverse effects of light therapy on pregnancy.

These data provide evidence that morning light therapy has an antidepressant effect during pregnancy. A randomized controlled trial is warranted to test this alternative to medication.

Limitations: Small N: 16 patients, Antepartum depression

IMPROVE RECOVERY PROCESS: REDUCE PAIN:

Walch, J.M., Rabin, B.S., Day, R., Williams, J.N., Choi, K., & Kang, J.D. (2005). The effect of sunlight on post operative analgesic medication usage: A prospective study of spinal surgery patients. Psychosomatic Medicine, 67 (1), 156-163.

Objective: The aim was to evaluate whether the amount of sunlight in a hospital room modifies a patient's psychosocial health, the quantity of analgesic medication used, and the pain medication cost.

Method: Part of the evaluation was quantitative survey, the other part qualitative survey. The intensity of sunlight in each hospital room was measured daily and psychologic questionnaires were administered on the day after surgery.

Results: Patients staying on the bright side of the hospital unit were exposed to 46% higher intensity sunlight on average ($p = .005$). Patients exposed to an increased intensity of sunlight experienced less perceived stress ($p = .035$), marginally less pain ($p = .058$), took 22% less analgesic medication per hour ($p = .047$), and had 21% less pain medication costs ($p = .047$). Age quartile was the only other variabl found to be a predictor of analgesic use, with a significant negative correlation ($p < .001$). However, patients housed on the bright side of the hospital consistently used less analgesic medications in all age quartiles. The exposure postoperatively of patients who have undergone spinal surgery to increased amounts of natural sunlight during their hospital recovery period may result in decreased stress, pain, analgesic medication use, and pain medication costs.

Limitations: Only patients undergoing elective cervical and lumbar spinal surgery were part of the evaluation.

Malenbaum, S., Keefe, F. J., Williams, A. C., Ulrich, R., and Somers, T. J. (2008). Pain in its environmental context: Implications for designing environments to enhance pain control. Pain, 134, 241–244

REDUCE STRESS:

Leather, P., Pyrgas, M., Beale, D., & Lawrence, C. (1998). Windows in the workplace: Sunlight, view, and occupational stress. Environment & Behavior, 30(6), 739–762.

Objective: This article investigates the direct and indirect effects of windows in the workplace on

job satisfaction, intention to quit, and general well-being.The impacts of three specific influencing mechanisms are examined: general level of illumination, sunlight penetration, and view. The sample consisted of 100 white-and blue-collar workers who were employed in a large wine-producing organization in the Mediterranean region of Southern Europe.

Results: The study showed a significant direct effect for sunlight penetration on job satisfaction, intention to quit, and general well-being. A view of natural elements (i.e., trees, vegetation, plants, and foliage) was found to buffer the negative impact of job stress on intention to quit and to have a similar, albeit marginal, effect on general well-being. No effects for general level of illumination were found.

Alimoglu, M. K., & Donmez, L. (2005). Daylight exposure and the other predictors of burnout among nurses in a university hospital. International Journal of Nursing Studies, 42(5), 549–555.

Objective: The purpose of the study was to investigate the possible direct or indirect effects of daylight exposure on burnout.

Methods: Questionnaire. 141 nurses were asked to complete a personal data collection form to collect data about their burnout, work-related stress and job satisfaction levels in addition to personal characteristics.

Results: Daylight exposure showed no direct effect on burnout but it was indirectly effective via WRS and JS. Exposure to daylight at least 3 h a day was found to cause less stress and higher satisfaction at work. Suffering from sleep disorders, younger age, job-related health problems and educational level were found to have total or partial direct effects on burnout. Night shifts may lead to burnout via work related strain and working in inpatient services and dissatisfaction with annual income may be effective via job dissatisfaction.

This study confirmed some established predictors of burnout and provided data on an unexplored area. Daylight exposure may be effective on job burnout.

Limitations: The Study took place in an University hospital in Turkey.

INCREASE MOOD/ SATISFACTION

Kueller R, Ballal S, Laike T, Mikellides B, Tonello G. The impact of light and colour on psychological mood: a cross-cultural study of indoor work environments. Ergonomics. 2006 Nov 15;49(14), 1496-507.

Mroczek, J., Mikitarian, G., Vieira, E. K., & Rotarius, T. (2005). Hospital design and staff perceptions: An exploratory analysis. Health Care Manager, 24(3), 233–244.

Scott, H. (2004). Working environments have a direct impact on care. British Journal of Nursing, 13, 893.
Harris, P. B., McBride, G., Ross, C., & Curtis, L. (2002). A place to heal: Environmental sources of satisfaction among hospital patients. Journal of Applied Social Psychology, 32(6), 1276–1299.

Kim, J.J. & Wineman, J. (2005) Are Windows and Views Really Better? A quantitative Analysis of the Economic and Psychiological Value of Views.

IMPROVE PERFORMANCE

Figueiro, M. G., Rea, M. S., Stevens, R. G., Rea, A. C. (2002). Daylight and productivity - a possible link to circadian regulation. The Lighting Research Office of the Electric Power Research Institute (2002), 185-193.

Objective: The present pilot study compared occupancy rates and types of behavior in matched samples of office workers assigned to interior or to windowed offices during the winter of 2001.
Method: Experimental Research/ Observation Research
Results: Although occupancy rates were identical, workers in windowed offices spent more time on computer tasks, less time talking on the telephone and to coworkers than matched workers in interior offices. The root cause of these findings remains unknown, but the results are consistent with the hypothesis that bright light during the day improves productivity during winter months.
Limitations: The study took place in New York and included 120 desks in 81 different offices.

Heschong Group 2003
Windows and Offices: A study of Office Worker Performance and the Indoor Environment

Boyce, P., Rea, M.S. 2001
Lighting and Human Performance

Heerwagen, J. H. DESIGN, PRODUCTIVITY AND WELL BEING: What are the Links? !1998) Paper presented at: The American Institute of Architects Conference on Highly Effective Facilities Cincinnati, Ohio, March 12-14, 1998

INCREASE CONCENTRATION

Heschong, L. et al. 2003: Windows and Classrooms: A study of Student Performance and the Indoor Environment.

Result: Data of 21.000 students shows that students in classrooms with most daylighting progressed 20 percent faster on math tests and 26 percent faster on reading tests than students in classrooms with no daylight. A 15 percent faster performance in math and 23 percent in reading was found for students in rooms with the greatest window area than those with the least. Students in classrooms with a skylight and diffuse daylight distribution were 19-20 percent faster than students in rooms with no skylight.

REDUCE MEDICAL ERRORS

Buchanan, T. L., Barker, K. N., Gibson, J. T., Jiang, B. C., & Pearson, R. E. (1991). Illumination and errors in dispensing. American Journal of Hospital Pharmacy, 48(10), 2137-2145.

Objective: The relationship between the level of illumination and the prescription-dispensing error rate in a high-volume Army outpatient pharmacy was investigated. The prescription error rate was determined by direct, undisguised observation and retrospective prescription review under three levels of illumination (45, 102, and 146 foot-candles).
Results: The overall prescription error rate (including both content and labeling errors) was 3.39%

(369 prescriptions). An illumination level of 146 foot-candles was associated with a significantly lower error rate (2.6%) than the baseline level of 45 foot-candles (3.8%). The Conclusion of the study is that the rate of prescription-dispensing errors was associated with the level of illumination.

AVOID FATIGUE

Figueiro, M. G., Rea, M. S., Stevens, R. G., & Rea, A. C. (2002). Daylight and productivity - a possible link to circadian regulation. The Lighting Research Office of the Electric Power Research Institute (2002), 185-193.

REDUCE ENERGY CONSUMPTION:

Newsham, G.R., (1994). Manual Control of Window Blinds and Electric Lighting: Implications for Comfort and Energy Consumption. Indoor and Built Environment, Vol. 3, No. 3, 135-144 (1994)

Objective: The paper examines the impact of manual control on model predictions of thermal comfort and building energy consumption.

Method: Simulation

Results: The conclusion of the study is that lighting energy savings of around 30% are typical for small offices, but vary widely depending on the size and type of windows, and the motivation and preferences of the occupant(s)

Limitation: The study took part in Toronto, Canada

Reinhart, C.F. (2002). Effects of interior design on the daylight availability in open plan offices. National Research Council of Canada, Internal Report, NRCC-45374, NRC: Ottawa

Objective: The paper describes the influence or various design variables on the daylight availability and electric lighting requirements in open plan office space.

Method: Simulation

Results: This study shows that automatic systems that switch off or dim the lights in response to daylight are highly effective in single daylit offices. The research found that energy savings of 50% were possible in conjunction with a manually-operated blind system,and that savings could reach 70% if the blind were optimally controlled either by occupants or by an automatic system.

Roisin, B., Bodart, M., Deneyer, A., D'Herdt, P. (2008). Lighting energy savings in offices using different control systems and their real consumption. Energy and Buildings, Volume 40, Issue 4, 2008, Pages 514-523

Objective: This paper compares the potential of lighting energy savings in office rooms by using different control systems, for three locations in Europe and the four main orientations.

Methods: DAYSIM simulations are used to perform daylight calculations. Further, laboratory measurement are taken to evaluate precise system energy consumption. To stimulate a close-loop daylight dimming system, a new algorithm is implemented.

Results: It appears that the control of the electrical power in function of daylight leads to very high savings; they slightly depend on the room orientation and the location. Savings vary from 45 to 61%. The performances of an occupancy sensor are also tested. Threshold values of occupancy rate for which daylight dimming leads to higher gains than an occupancy control system vary between 27 and 44% depending on location and orientation.

Thirugnanasambandam, M., Iniyan, S., Goic, R. (2010). A review of solar thermal technologies. Renewable and Sustainable Energy Reviews, Volume 14, Issue 1, January 2010, Pages 312-322

Objective: Of all the renewable sources of energy available, solar thermal energy is the most abundant one and is available in both direct as well as indirect forms.

This paper reviews the present day solar thermal technologies. Performance analyses of existing designs (study), mathematical simulation (design) and fabrication of innovative designs with suggested improvements (development) have been discussed.

Method: Literature survey of the present day solar thermal technologies.

Results: The paper points out the areas in solar thermal technologies where there is scope for future research.

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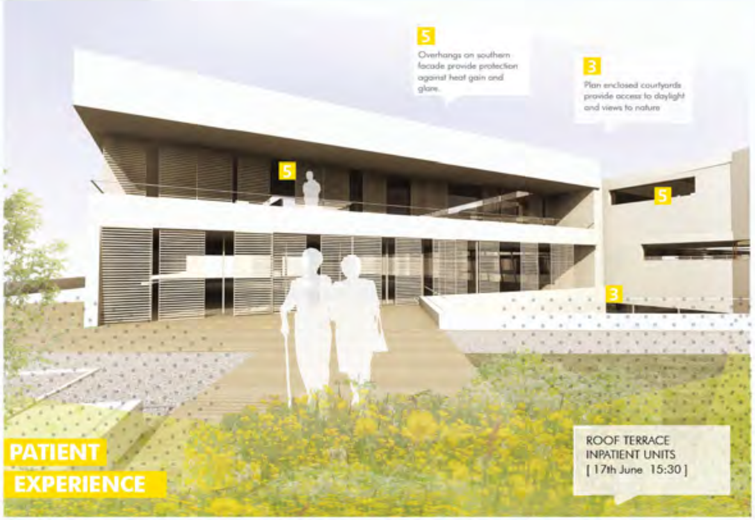
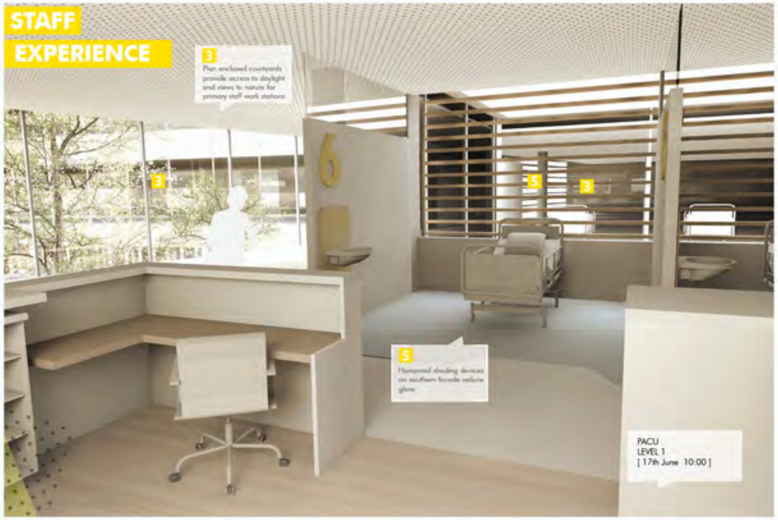
DAYLIGHT HOSPITAL
COURTYARD IN INPATIENT UNIT
MAIN SPINE WITH CLERESTORIES TOWARDS CENTRAL COURTYARD
NARROW BUILDING FOOTPRINT FOR OUTPATIENT CLINIC
INDIVIDUAL SHADING STRATEGIES FOR EACH DIRECTION
BIRDS VIEW
[23th March 15:30]


VISITOR EXPERIENCE
5
Sliding shutters on east facing facade provide protection against heat gain and glazing
5
Overhang helps to control exposure to sun on southern facade
5
5
ROOF TERRACE
LABOR & DELIVERY
[23th March 9:00]


5
Overhangs on southern facade provide protection against heat gain and glare.
3
Plan enclosed courtyards provide access to daylight and views to nature
5
5
3
ROOF TERRACE
INPATIENT UNITS
[17th June 15:30]
PATIENT EXPERIENCE


STAFF EXPERIENCE
3
Plan enclosed courtyards provide access to daylight and views to nature for primary staff work stations
3
6
5
3
5
Horizontal shading devices on southern facade reduce glare
PACU
LEVEL 1
[17th June 10:00]